The Inshore Fish Fauna of Johnston Island, a Central Pacific Atoll[1]

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INTRODUCTION

THIS PAPER is primarily concerned with Central Pacific zoogeography. Its main purpose is to trace in so far as possible the derivation and the immigration and emigration routes of the Johnston Island inshore fish fauna. The importance of Johnston for a study of this sort lies in its position between the areas inhabited by the great tropical Pacific fauna to the south and the strongly endemic Hawaiian fauna to the north (Fig. 1).

The first section of this paper records the fishes known from Johnston and presents the taxonomic interpretations upon which the zoogeographic treatment of the second section is based.

Of the collections dealt with, the most important for this paper are those taken by V. E. Brock, Y. Yamaguchi, and the author at Johnston in February 1951. These collections were made possible through the kindness of Colonel Cronau, then commanding officer of the island, and were greatly facilitated by Lt. Col. Eaton and other members of the airforce who were there at the time. In addition, three small collections from the same island were turned over to me by Brock, Schaefer, and Francis respectively. Finally, a reexamination of certain fishes from Johnston recorded by Fowler and Ball (1925) was made possible through the courtesy of the staff of the Bernice P. Bishop Museum.

SECTION 1. FISHES RECORDED FROM JOHNSTON ISLAND

Except for Schultz's (1950: 548) reference to *Cirrhitus alternatus*, the following four works include or cite all of the published records on Johnston fishes.

Smith and Swain (1882) recorded 27 species from the island, 5 of which they described as new.

Fowler and Ball (1925) listed 72 species from Johnston collected by the "Tanager" Expedition of 1923. One of these was described as new.

Schultz and collaborators (1953) in the first volume of their report on "Fishes of the Marshall and Marianas Islands" recorded specimens of about 9 Johnston species. Most of these were referred to only in passing, e.g., in tables; three, however, were described as new.

Halstead and Bunker (1954), in a report on fish poisoning at Johnston Island, listed 60 species investigated.

One hundred and eighteen species of Johnston fishes have been seen by the present author. Species recorded from the island that have not been seen are marked in the species accounts with an asterisk; some of these almost certainly represent misidentifications and others equally certainly do not, but any attempt to decide which are which would only lead to further misidentifications.

It is easy to criticize others for recording species without also providing sufficient descriptive material to determine whether the record has been correctly identified. It is more

difficult to write a paper that does not commit the same error and is still sufficiently brief to be publishable. The present account attempts a compromise between these two pitfalls. Species which are sufficiently distinct to be readily recognizable, about which there are at present no zoological or nomenclatorial questions, and whose presence at Johnston there is no zoogeographic reason to doubt, have been recorded by name only. For the others an attempt has been made to give the diagnostic characters of the Johnston specimens on the basis of which the species identification was made. It is clearly recognized that this method only alleviates, and by no means eliminates, the faults of recording species by name only.

This section contains notes on the classification of certain species of *Uropterygius*, *Belone*, *Pseudamiops*, *Scarus*, and *Scorpaena* as well as the records of Johnston fishes. Families are listed in "phylogenetic sequence"; genera and species within the family are taken up alphabetically. Identifications and nomenclature follow Schultz, *et al.* (*op. cit.*) where possible, and various authors for the remaining species. All lengths given in millimeters are standard lengths; total lengths are expressed in inches.

MYLIOBATIDAE

Aetobatus narinari (Euphrasen)
   Fowler and Ball, 1925, 1 spec.; Halstead and Bunker, 1954, 1 spec.

SYNODONTIDAE

Saurida gracilis (Quoy and Gaimard)
   5 specs., 69–110 mm., 1951; 1 spec., Brock, 1948.
   A double band of teeth on each side of the palate; inner rays of pelvic fins contained about 1.2 times in the length of the outermost rays.

Synodus binotatus Schultz
   3 specs., 46–77 mm., 1951.
   A single row of teeth on each side of

palate; three and a half scale rows between the lateral line and the dorsal origin; peritoneum pale; no black spot on opercle but a dark mark on tip of snout and three dark rings on the back behind the dorsal fin; 9 anal rays; tips of first dorsal rays not reaching tips of succeeding rays when the fin is depressed; dorsal origin equidistant from tip of snout and origin of adipose; tips of central caudal rays not black (cf., Schultz, *et al.*, 1953: 30, 31).

CONGRIDAE

Conger noordziekii Bleeker
   1 spec., 255 mm., 1951.
   Origin of dorsal over anterior third of the depressed pectorals; a dark longitudinal line extending below and behind eye.

OPHICHTHIDAE

Brachysomophis sauropsis Schultz
   1 spec., 362 mm., 1951.
   As compared with a 1070 mm. specimen of *Brachysomophis henshawi* from Hawaii, the Johnston specimen differs in having the distance from the tip of snout to the posterior border of the eye contained 9 times in the head length to gill openings instead of 7.2 times, in having the dorsal and anal fins low (the anal does not even extend above the groove that encloses it) and light in coloration instead of well-developed and with the dorsal black-based; in having the pores of the head and body not enclosed in dark areas; and in having no dark bands either along the mid-dorsal line or along the lateral line area of the sides. The Johnston specimen agrees in every way with Schultz's original description of *Brachysomophis sauropsis*.

Leiuranus semicinctus (Lay and Bennett)
   6 specs., 133–227 mm., 1951. Fowler and Ball, 1925, 3 specs.
   Ovate black saddles about equal in maximum width to the interspaces between them.

Leptenchelys labialis (Seale)
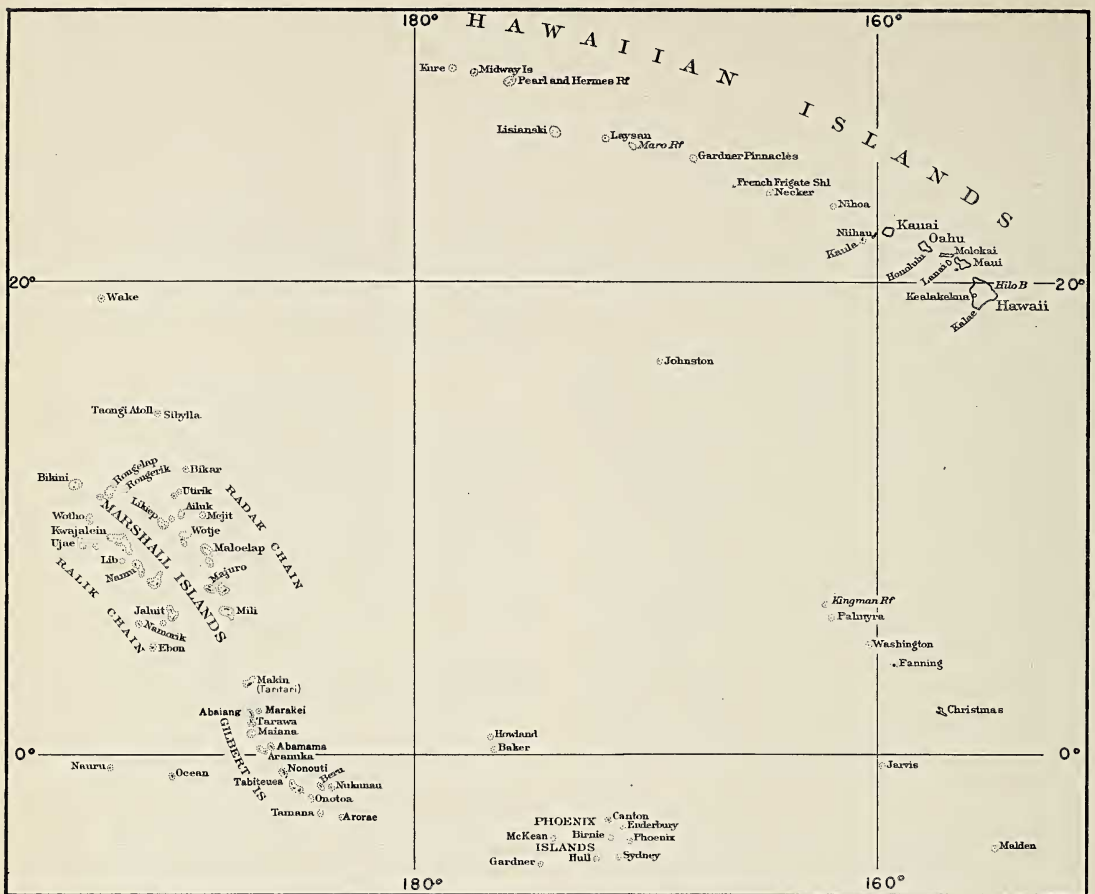   2 specs., 121–134 mm., 1951.

FIG. 1. Chart of the region surrounding Johnston Island. From U. S. Hydrographic Chart 1500, 47th edition.

Ventral surface of snout with a median groove that contains teeth; caudal fin well developed; dorsal origin a little over a head length behind head (cf., Schultz, *et al.*, 1953: 71).

I have dealt elsewhere (1950: 312–314; 1952: 300–306) at some length with the reasons why *Leptenchelys*, *Muraenichthys*, and *Schultzidia* should be placed in the Ophichthidae.

Muraenichthys cookei Fowler

12 specs., 103–173 mm., 1951.

Posterior rim of orbit about over rictus; dorsal origin from 2 to 5 eye diameters ahead of anus; vomerine teeth uniserial (cf., Schultz, *et al.*, 1953: 71, 72).

These specimens are discussed in section 2.

Muraenichthys gymnotus Bleeker

3 specs., 52–118 mm., 1951.

Dorsal fin originating about half a head length behind the anus; rear margin of eye slightly ahead of rictus; teeth on front of maxillary and dentary at least double-rowed; snout sharp, the distance from its tip to the rictus contained about 3.7 times in the head length (cf., Schultz, *et al.*, 1953: 71–73).

Muraenichthys schultzei Bleeker

3 specs., 106–117 mm., 1951. Fowler and Ball, 1925, 12 specs.

Dorsal origin about two-thirds of a head length behind anus; snout bluntly rounded; vomerine teeth two-rowed (cf., Schultz, *et al.*, 1953: 71–73).

Myrichthys bleekeri Gosline

1 spec., 365 mm., 1951. As *Myrichthys colubrinus*, Fowler and Ball, 1925, 12 specs.

Width of black band over gill opening contained two times in the white interspace behind it; only the last two bands completely encircling the body.

Myrichthys maculosus (Cuvier)

5 specs., 275–865 mm., 1951. Fowler and Ball, 1925, 1 spec. As *Myrichthys stypurus* Smith and Swain, 1882, 1 spec.

Round black spots on a greenish background.

Schultzidia johnstonensis (Schultz and Woods)

2 specs., 101–167 mm., 1951. Schultz, *et al.*, 1953, 1 spec.

Maxillary teeth small, in several rows, facing inward; vomerine teeth minute in the small specimen, apparently absent in the larger; no median papilla on upper lip between nostrils (cf., Schultz, *et al.*, 1953: 71).

MORINGUIDAE

Moringua macrochir Bleeker

5 specs., 128–262 mm., 1951.

Lower jaw projecting; lateral line pores 98–110.

The name used for this species follows Gosline and Strasburg (In press).

MURAENIDAE

Anarchias allardicei Jordan and Starks

5 specs., 121–135 mm., 1951.

Pore near posterior nostril lying somewhat ahead of nostril; body color plain brown, the brownish color provided by microscopic brown speckling on a light background (cf., Schultz, *et al.*, 1953: 139).

Anarchias cantonensis (Schultz)

3 specs., 142–163 mm., 1951.

Pore near posterior nostril lying somewhat ahead of nostril; body with a reticulate pattern of dark on light; chin barred (cf., Schultz, *et al.*, 1953: 139).

Anarchias leucurus (Snyder)

35 specs., 103–176 mm., 1951.

Pore near posterior nostril lying slightly behind nostril; body with a reticulate pattern; chin barred (cf., Schultz, *et al.*, 1953: 139).

Echidna leucotaenia Schultz

5 specs., 150–240 mm., 1951.

Body plain brown; fins black-based and white-edged; lower jaw light except for a brown patch below each eye (cf., Schultz, *et al.*, 1953: 100).

Echidna polyzona (Richardson)

1 spec., 63 mm., 1951.

Pebble-like teeth on vomer; about 27 dark bands on body (cf., Schultz, *et al.*, 1953: 100).

Echidna zebra (Shaw)

1 spec., 850 mm., 1951.

Anus well behind middle of body length; black and white stripes on body (cf., Schultz, *et al.*, 1953: 100).

***Gymnothorax buroensis** Bleeker

Halstead and Bunker, 1954, 5 specs. It seems most likely that Halstead and Bunker's record refers to *Gymnothorax eurostus*, the Hawaiian form of *G. buroensis*. Indeed, since none of the Hawaiian "endemic" species are recorded by Halstead and Bunker, such of this element in the Johnston fauna as was taken by these authors must have been misidentified.

Gymnothorax eurostus (Abbott)

20 specs., 158–500 mm., 1951.

Premaxillary teeth divisible into 5 series, these somewhat difficult to distinguish in large specimens; no black blotch surrounding gill opening; body mottled (cf., Schultz, *et al.*, 1953: 109).

These specimens are dealt with in section 2.

Gymnothorax gracilicaudus Jenkins

3 specs., 106–140 mm., 1951.

Teeth not serrate, in three series on premaxillary, those of the median row notably enlarged. Body light with irregular dark ver-

tical bands; no black blotch around gill opening; a prominent white band down the midline of the snout; median fins with broad, plain, light borders; dark pigment forming an irregular band extending from behind eye across rictus; chin and abdomen light; a dark saddle running across top of head and down at least to the level of the eye on either side.

*Gymnothorax javanicus (Bleeker)

Halstead and Bunker, 1954, 2 specs.

Gymnothorax meleagris (Shaw)

3 specs., 230–670 mm., 1951. Fowler and Ball, 1925, 2 specs.; Halstead and Bunker, 1954, 2 specs.

Five rows of teeth on premaxillary; gill opening in a black area; small, round, white spots on a dark ground.

Gymnothorax moluccensis (Bleeker)

1 spec., 257 mm., 1951.

Larger, lateral teeth in both jaws serrate. Body plain brown (cf., Schultz, *et al.*, 1953: 109).

Gymnothorax pictus (Ahl)

As *Lycodontis picta*, Fowler and Ball, 1925, 2 specs., one of these reexamined.

Gymnothorax undulatus (Lacépède)

2 specs., 250 and 850 mm., 1951.

Premaxillary teeth in three series, the central teeth fang-like. Body dark, with narrow white reticulations forming irregular vertical lines; no white streak on snout (cf., Schultz, *et al.*, 1953: 109–113).

Rabula fuscomaculata Schultz

19 specs., 116–149 mm., 1951. Schultz, *et al.*, 1953, 16 specs.

Dorsal fin commencing somewhat less than a head length ahead of anus; dark spots and reticulations on a light ground (cf., Schultz, *et al.*, 1953: 139).

Uropterygius dentatus Schultz

1 spec., 366 mm., 1951. Schultz, *et al.*, 1953, 373 mm., holotype.

Mottled with dark spots, those posteriorly more or less united into irregular vertical bars; vomerine teeth either absent or made up of a short posterior continuation of the median premaxillary row; both anterior and posterior nostrils pigmented though less so than the rest of the head; gill opening high on the sides.

This specimen seems to be more or less intermediate between *U. dentatus* and *U. supraforatus*. Indeed the distinctions between these two species as given by Schultz (in Schultz, *et al.*, 1953: 141) do not seem to be very clear-cut. Nevertheless, it seems best to follow Schultz in recognizing the Johnston form as *U. dentatus*, at least until such time as specimens of *U. supraforatus* become available for comparison.

For the relationships between *U. dentatus* and *U. fuscoguttatus*, see the account of the latter species.

Uropterygius fuscoguttatus Schultz

3 specs., 129–152 mm., 1951. Schultz, *et al.*, 1953, 1 spec.

At the present time there seem to be three recognized Central Pacific species in the *Uropterygius* group with the gill openings high on the sides and multiserial teeth in both jaws: *U. supraforatus* Regan, *U. dentatus* Schultz, and *U. fuscoguttatus* Schultz. Unfortunately, Schultz has placed his two species, both of which according to specimens and his own figures (in Schultz, *et al.*, 1953: figs. 32, 33) have the gill opening about equally high on the sides, on opposite sides of a major break in his key based on the level of the gill openings. Actually *U. fuscoguttatus* is rather difficult to distinguish from *U. supraforatus* and *U. dentatus*. As compared with these, *U. fuscoguttatus*, judging from Hawaii and Johnston material, is a relatively small species, not attaining a length of over 285 mm. A female 185 mm. is ripe. From *U. dentatus* it can best be distinguished by coloration: *U. dentatus* is an eel with dark spotting and mottling everywhere; *U. fuscoguttatus*, by contrast, is spotted and mottled posteriorly, but the head and fore-

part of body are plain brown, the brownish color made up of minute, regularly spaced punctulations. In addition *U. fuscoguttatus* has a somewhat longer snout; the distance between the posterior margin of the eye and the most posterior maxillary tooth is considerably less than the distance from the tip of the snout to the posterior nostril (in *U. dentatus* these two distances are about equal). In *U. dentatus* the two jaws are about equal, and the distance from the tip of chin to the most posterior mandibular tooth is contained about 2.4 times in the head length; in *U. fuscoguttatus* the lower jaw is very slightly inferior, and the distance from the tip of the chin to the last mandibular tooth is contained about 2.7 times in the head length. There are also many more teeth in *U. dentatus* than in *U. fuscoguttatus* but since the teeth are multiserial in both species, this difference is difficult to quantify. The features listed above would be adequate for distinguishing the two species if they were the same size. Unfortunately they are not. The largest known specimen of *U. fuscoguttatus* is one from Hawaii measuring 285 mm.; the smallest of the three known specimens of *U. dentatus* is 363 mm.

Uropterygius polyspilus Regan

2 specs., 150 and 180 mm., 1951.

Anus very slightly behind middle of the total length; prominent, roundish dark spots on a light brown background; tip of snout white in alcohol, yellow in life.

Uropterygius tigrinus (Lesson)

2 specs., 670 and 680 mm., 1951. As *Gymnomuraena tigrina*, Smith and Swain, 1882, 1 spec.

Anus far behind middle of total length; prominent, roundish dark spots on a light brown background; snout of the same color as the rest of the body but speckled rather than spotted.

BELONIDAE

Belone platyura Bennett

1 spec., 295 mm., 1951. Halstead and Bunker, 1954, 1 spec. As *Belone persimilis*, Schultz, *et al.*, 1953, 4 specs.

The relationship between *Belone platyura* and *B. persimilis* needs clarification. *B. persimilis* was first differentiated from *B. platyura* by Günther (1909: 340, text fig.) on the basis of the smaller eye. In order to demonstrate this, Günther compared the eye size with the interorbital and with the postorbital head length in the two species (Table 1). In 1943 Schultz (p. 54) placed *B. persimilis* in the synonymy of *B. platyura*, stating: "After measuring a large series of specimens of the large-eyed form *B. platyura* and many of the small-eyed form named by Günther *B. persimilis*, I am of the opinion that when small this species has a small eye and when larger the eye is much larger in proportion." In 1953 Schultz (p. 160) reseparated the two nominal species on the basis of eye size and the relatively shorter postorbital head length of *B. persimilis*. He compared these two characters with one another and each of them with the distance between the pelvic insertion and the anal origin in the two species (Table 1). Whereas Günther believed the two species occurred together over a wide area, Schultz (1953, *loc. cit.*) considered all of his Marshallese material to represent *B. platyura* and all of the Johnston (and by inference Hawaiian) specimens to be *B. persimilis*.

Counts and measurements of the six specimens available to me are given in Table 1. Aside from the characters listed, an attempt was made to find others which might be used for differentiating two species. For example, the length of the anal base was compared with the postanal length, but it was found that this comparison merely demonstrated the difference in the number of anal rays. Again, the Johnston and the larger Hawaiian specimen at present lack cheek scales whereas the other four have such scales, but this may be an artifact of preservation. At first it was thought possible to separate a long, narrow-headed species from one with a relatively short and broad head (the smaller Hawaiian and the

TABLE 1

Certain Counts, Measurements, and Differences between *Belone persimilis?* and *Belone platyura*
Measurements, except the first, are given in thousandths of the body length as defined

	Belone persimilis?			*Belone platyura*		
	Oahu	Oahu	Johnston	Gilberts	Gilberts	Bikini
Body length, from front of eye to tip of fleshy projection on middle caudal rays.	255 mm.	272 mm.	299 mm.	230 mm.	278 mm.	297 mm.
Distance from front of nasal bones to anterior nostril.	35.3	34.5	36.8	33.3	38.1	36.4
Horizontal orbit diameter.	45.2	45.0	44.2	46.1	47.8	50.2
Postorbital head length.	76.2	76.8	73.4	81.3	82.8	77.7
Width of skull in front of eye.	51.1	50.9	51.2	46.5	56.8	57.2
Width of bony interorbital.	36.5	37.0	34.5	39.1	43.8	43.1
Maximum width of skull across pterotics.	52.5	53.7	53.2	45.9	62.2	62.3
Distance from pelvic insertion to anal origin.	184	182	181	189	192	174
Dorsal rays.	14	14	14	13	14	14
Anal rays.	18	19	19	17	18	18
Pectoral rays.	12	12	12	12	12	12
Orbit into bony interorbital:						
Present data.		0.81 to 1.1			0.85 to 0.92	
According to Günther (1909).	less than (soft?) interorbital			equals (soft?) interorbital		
Orbit into postorbital head:						
Present data.		1.67 to 1.70			1.55 to 1.75	
According to Günther (1909).		1.6 to 2			1.5 to 1.67	
According to Schultz (1953).		1.8 to 2.1			1.5 to 1.8	
Orbit into pelvic-anal distance						
Present data.		4.1 to 4.2			3.5 to 4.1	
According to Schultz (1953).		4.0 to 5.1			3.1 to 3.6	
Postorbital head length into pelvic-anal distance:						
Present data.		2.3 to 2.5			2.2 to 2.3	
According to Schultz (1953).		2.3 to 2.5			2.0 to 2.2	

smaller Gilbertese specimen would constitute the narrow-headed form) but this idea was discarded. In the final analysis it appears that if any separation of two species among the tabulated specimens is made, it should be based on the size of the eye. However, the difference in eye size between the specimens in Table 1 labelled *B. persimilis?* and those labelled *B. platyura* is very slight, and from the Table it is obvious that to state this difference in relation to the interorbital width, the postorbital head length, and only to a lesser extent the pelvic-anal distance obscures rather than clarifies the segregation of two forms. In short, of the characters used by Günther and by Schultz (1953), only two of them will serve to separate the specimens at hand, and even in these there may prove to be more of a continuous distribution than a separation. Under the circumstances it seems that a convincing means of differentiating *B. persimilis* from *B. platyura*, if both species are valid, remains to be demonstrated; meanwhile there is little practical use in recognizing them. Finally, if the two prove valid, then the nomenclatorial question will arise as to whether the second should be called *B. persimilis*, *B. carinata* (described from the Hawaiian Islands by Cuvier and Valenciennes in 1846), or perhaps by some other early name.

HEMIRAMPHIDAE

Hyporhamphus acutus (Günther)
2 specs., 80 and 163 mm., 1951.

Upper jaw scaled; greatest diameter of the nasal fossa about one third the diameter of the orbit; posterolateral border of fossa with a prominent bony rim; sensory pore on preorbital apparently branched above with a pore in front of eye and another near nasal fossa; inner pelvic ray not elongate. Dorsal base very slightly shorter than base of anal; dorsal with 14 rays, anal with 18 in larger specimen.

The identification of these specimens seems certain, except that the small diameter of the nasal fossa throws them into the genus *Hemiramphus* according to Schultz and Woods' generic key (in Schultz, *et al.*, 1953: 166). Measurement of other available specimens of the same species including Bikini duplicates indicates that the key character referred to will not serve for this species.

EXOCOETIDAE

Cypselurus poecilopterus (Valenciennes)
  Fowler and Ball, 1925, 2 specs.

Cypselurus simus (Valenciennes)
  Fowler and Ball, 1925, 1 spec.

AULOSTOMIDAE

Aulostomus chinensis (Linnaeus)
  Smith and Swain, 1882, 1 spec.; Halstead and Bunker, 1954, 5 specs.

FISTULARIIDAE

Fistularia petimba Lacepède
  1 spec., 900 mm., 1951. Fowler and Ball, 1925, 1 spec.

HOLOCENTRIDAE

Holocentrus lacteoguttatus Cuvier
  10 specs., 54–109 mm., 1951; 2 specs., 97 and 101 mm., Brock, 1948. Fowler and Ball, 1925, 5 specs.; Halstead and Bunker, 1954, 2 specs.
  The two opercular spines subequal in size; body speckled with sooty marks.

Holocentrus microstomus Günther
  Fowler and Ball, 1925, 2 specs., one of these reexamined.

Dorsal XI–12; perforated scales in lateral line 48; longest anal spine reaching beyond caudal base.

Holocentrus sammara (Forskål)
  3 specs., 117–157 mm., 1951. Halstead and Bunker, 1954, 1 spec.
  Brown spotting on a bronze to silvery background; a large dark blotch on the spinous dorsal.

Holocentrus spinifer (Forskål)
  4 specs., 151–300 mm., 1951; 1 spec., 261 mm., Schaefer, 1948. Fowler and Ball, 1925, 6 specs.; Halstead and Bunker, 1954, 7 specs. As *Holocentrus leo*, Smith and Swain, 1882, 2 specs.

Holocentrus tiere Cuvier and Valenciennes
  8 specs., 121–226 mm., 1951. Halstead and Bunker, 1954, 3 specs. As *Holocentrus erythraeus*, Smith and Swain, 1882, 2 specs.
  Perforated scales in the lateral line 50; maxillary longer than eye; dorsal XI–14.

Holotrachys lima (Valenciennes)
  1 spec., 115 mm., 1951.

Myripristis argyromus Jordan and
  Evermann
  31 specs., 45–210 mm., 1951; 1 spec., 121 mm., Brock, 1948. Halstead and Bunker, 1954, 3 specs. As *Myripristis murdjan*, Fowler and Ball, 1925, 1 spec., this specimen reexamined.
  Perforated scales in the lateral line 34; anal IV, 13; gill rakers 12 + 1 + 25 = 38; interorbital width contained about 3.7 times in the head length.

*Myripristis berndti Jordan and Evermann
  Halstead and Bunker, 1954, 1 spec.

APOGONIDAE

Apogon erythrinus Snyder
  15 specs., 30–42 mm., 1951.
  Dorsal VI–I, 9; anterior margin of preopercle smooth; anal II, 8; lateral line complete; second spine of first dorsal much longer than third (cf., Lachner, *in* Schultz, *et al.*, 1953: 435).

Apogon menesemus Jenkins

13 specs., 67–128 mm., 1951; 1 spec., 86 mm., Brock, 1948.

Dorsal VII–I, 9; both margins of preopercle serrate; palatine teeth absent; gill rakers (including rudiments) 4 + 1 + 17 = 22; black pigmentation on caudal forming a complete arc.

Apogon snyderi Jordan and Evermann

31 specs., 32–100 mm., 1951; 2 specs., 40 and 97 mm., Brock, 1948. As *Apogon frenatus*, at least in part, Fowler and Ball, 1925, 6 specs.

Dorsal VII–I, 9; both margins of preopercle serrate; palatine teeth present; gill rakers (including rudiments) 4 + 1 + 13 = 18; no circular spot at midbase of caudal fin in specimens over 55 mm. but instead a dark bar that covers the whole fin base; in specimens 50–55 mm. a more or less well-delimited, round dark spot that lies above but touches the lateral line; stripe on sides not well-marked, absent in large specimens; serrations on anterior margin of preopercle reaching a larger size than those on posterior margin; suborbital serrations few in small specimens, numerous in large, but almost always more than 3 (cf., Lachner, in Schultz, *et al.*, 1953: 436, 437).

Apogon waikiki (Jordan and Evermann)

3 specs., 21–36 mm., 1951.

Dorsal VII–I, 9; no serrations on preopercle; palate toothless; lateral line complete; dorsal fin without ocellus; dorsal rounded, dusky at base, the tips of the outer rays white.

Pseudamiops gracilicauda (Lachner)

1 spec., 23 mm., 1951.

Recently Smith (1954) has described the new genus *Pseudamiops* for the single new species *P. pellucidus*. In the same article (p. 794) he erects the "provisional" genus *Lachneria* for the species *Gymnapogon gracilicauda* Lachner. The difference between the two genera according to the descriptions is that *Pseudamiops* is scaled and the specimens on which *Gymnapogon gracilicauda* was based were naked. Smith suspected that the scales of *G. gracilicauda* had been rubbed off; hence the provisional nature of his genus *Lachneria*. The specimen from Johnston plus two Hawaiian specimens agree well with Lachner's description of *Gymnapogon gracilicauda* except that they are more or less scaled. However, as with *Pseudamiops pellucidus*, the scales are apparently highly deciduous, for none of the three specimens are now completely scaled.

The chief points, aside from squamation, in which the Johnston and Hawaii specimens differ from Lachner's description and figure (in Schultz, *et al.*, 1953: 497, 498, fig. 84) are the following. The present specimens have a very pinched-in abdominal region as though the fishes had been starving; the specimen figured by Lachner does not have this feature, nor does that of *Pseudamiops* figured by Smith. The longest spine of the anal and that of the second dorsal are about half the length of the succeeding soft ray, instead of about four fifths the length of these rays as shown in Lachner's figure. The middle pectoral rays terminate in elongate, soft, fragile filaments. There seem to be at most 6 or 7 teeth on the vomer instead of about 20 according to Lachner (the vomerine teeth of *Pseudamiops* are reduced to one or two). There are no weak spines on the operculum; two are said to be present in *Gymnapogon gracilicauda*. Finally, only one of the three specimens has the system of papillae on the head well developed; however, as Smith has noted the prominence of this character probably varies with the nature of preservation.

From *Pseudamiops pellucidus* the Hawaiian and Johnston specimens differ in having one fewer soft anal ray and in lacking the pigment spots on the head.

It may prove to be that the Hawaiian and Johnston material is a separate species from both Lachner's Marshallese form and Smith's from Africa. However, as Lachner's material was in poor condition it will apparently require comparison with better Marshallese

material to determine whether the Hawaiian form is conspecific with it or not.

No such doubt seems possible regarding the necessity of placing the genus *Lachneria* in the synonymy of *Pseudamiops*.

KUHLIIDAE

Kuhlia marginata (Cuvier and Valenciennes)
9 specs., 61–221 mm., 1951. As *Kuhlia taeniura*, Smith and Swain, 1882, 2 specs.
These specimens will be dealt with in section 2.

PSEUDOCHROMIDAE

Pseudogramma polyacantha (Bleeker)
11 specs., 39–74 mm., 1951; 4 specs., 35–51 mm., Brock, 1948.
Dorsal spines VII; no enlarged pores between the eyes.

PRIACANTHIDAE

Priacanthus cruentatus (Lacepède)
2 specs., 127 and 140 mm., 1951; 4 specs., 89–93 mm., Francis, 1948. Halstead and Bunker, 1954, 2 specs.
Soft dorsal rays 13; soft anal rays 14; no dark spots on pelvic fins; caudal fin truncate.

SERRANIDAE

*Pristipomoides sieboldii
Fowler and Ball, 1925, 1 spec.

KYPHOSIDAE

*Kyphosus bigibbus Lacepède
Halstead and Bunker, 1954, 1 spec.

Kyphosus vaigiensis (Quoy and Gaimard)
1 spec., 170 mm., 1951.
Longest dorsal spine longer than longest soft dorsal ray; dorsal XI, 13; anal III, 12 or 13; greatest depth 2.3 in standard length.

MULLIDAE

*Mulloidichthys auriflamma (Forskål)
Halstead and Bunker, 1954, 2 specs. As *Upeneus vanicolensis*, Smith and Swain, 1882,

1 spec. As *Mulloides auriflamma* Fowler and Ball, 1925, 4 specs.

Mulloidichthys samoensis (Günther)
5 specs., 162–219 mm., 1951; 6 specs., 92–101 mm., Francis, 1948; 9 specs., 124–143 mm., Schaefer, 1948. Halstead and Bunker, 1954, 7 specs. As *Upeneus preorbitalis* Smith and Swain, 1882, 1 spec.
A black spot on sides below spinous dorsal; a dark area on inside of gill cover ahead of pseudobranch.

Parupeneus barberinus (Lacepède)
As *Upeneus barberinus*, Fowler and Ball, 1925, 1 spec., this reexamined.

Parupeneus bifasciatus (Lacepède)
8 specs., 53–210 mm., 1951. Halstead and Bunker, 1954, 3 specs. As *Parupeneus crassilabris*, Smith and Swain, 1882.
Depth of body greater than the head length; barbels short, failing to reach the pelvic bases by about three and a half scales; body usually with vertical dark bands, one of these with its anterior border about even with a line drawn between the soft dorsal and anal origins.

*Parupeneus chryserydros (Lacepède)
Halstead and Bunker, 1954, 2 specs. As *Upeneus chryserydros*, Fowler and Ball, 1925, 1 spec.

*Parupeneus crassilabris (Valenciennes)
Halstead and Bunker, 1954, 1 spec.

Parupeneus multifasciatus (Quoy and Gaimard)
3 specs., 175–220 mm., 1951. As *Upeneus velifer* Smith and Swain, 1882, 1 spec.
Depth of body less than the head length; barbels long, failing to reach the pelvic origins by 1 scale; body with dark vertical blotches, one of these with its anterior border extending downward and forward from the last ray of the first dorsal.

*Parupeneus trifasciatus (Lacepède)
Halstead and Bunker, 1954, 4 specs.

CIRRHITIDAE

Cirrhitus alternatus Gill
1 spec., 72 mm., 1951; 1 spec., 119 mm., Brock, 1948. As *Cirrhitus maculatus*, Fowler and Ball, 1925, 1 spec.

These specimens are dealt with in section 2.

Paracirrhites bimacula (Jenkins)
13 specs., 28–60 mm., 1951.

CARANGIDAE

Carangoides ferdau jordani Nichols
1 spec., 318 mm., 1951. Halstead and Bunker, 1954, 5 specs.

Teeth in bands in both jaws; breast naked; depth of body about 2.8 in standard length; anal soft rays 25; 20 gill rakers on lower portion of first arch (cf., Woods, in Schultz, *et al.*, 1953: 505).

*Caranx ascensionis (Osbeck)
Fowler and Ball, 1925, 4 specs.

*Caranx dasson Jordan and Snyder
Fowler and Ball, 1925, 1 spec.

*Caranx gymnostethoides (Bleeker)
Smith and Swain, 1882, 1 spec.

*Caranx lugubris Poey
Halstead and Bunker, 1954, 5 specs.

*Caranx melampygus Cuvier
Halstead and Bunker, 1954, 4 specs.

*Scomberoides sancti-petri (Cuvier)
Smith and Swain, 1882, 1 spec.; Fowler and Ball, 1925, 2 specs.

Trachurops crumenophthalmus (Bloch)
1 spec., 286 mm., 1951; 4 specs., 121–128 mm., Francis, 1948; 2 specs., 173 and 177 mm., Schaefer, 1948.

Shoulder girdle deeply furrowed.

POMACENTRIDAE

Abudefduf imparipennis (Vaillant and Sauvage)
20 specs., 33–50 mm., 1951. Fowler and Ball, 1925, 4 specs.

Preopercle smooth; teeth flattened at tips; dorsal XII, 15; color plain yellowish green; upper base of pectoral pale.

Abudefduf phoenixensis Schultz
2 specs., 50–51 mm., 1951. As *Abudefduf albofasciatus*, Fowler and Ball, 1925, 2 specs.

Preopercle smooth; teeth somewhat flattened at tips; dorsal XII, 18; anal II, 13; caudal peduncle encircled by a black band, followed abruptly by white on the remainder of the caudal peduncle and tail; a round black spot on the soft dorsal.

*Abudefduf sordidus (Forskål)
Fowler and Ball, 1925, 8 specs.; Halstead and Bunker, 1954, 7 specs.

Chromis leucurus Gilbert
2 specs., 61 and 65 mm., 1951; 1 spec., 68 mm., Brock, 1948. As *Chromis dimidiatus*, Fowler and Ball, 1925, 1 spec., 64 mm., this specimen reexamined.

This species is described herewith.

After much vacillation, these plain brown-bodied specimens with a black blotch at the pectoral base are here identified as a color

TABLE 2
Certain Counts for Two Forms of *Chromis leucurus*

FORM	LATERAL LINE SCALES			TOTAL GILL RAKERS					SOFT DORSAL RAYS			SOFT ANAL RAYS			PECTORAL RAYS		
	15	16	17	27	28	29	30	31	12	13	14	12	13	14	16	17	18
Black and white	2	3		1	2	1	1		2	14	2	2	12	4	1	4	
Plain brown	3	2	1	1	2			2		8		1	7		1	2	2

form of the black and white *Chromis leucurus.*
Comparison of the same two forms from Ha-
waiian material provides the following infor-
mation: (1) the black and white and the
brown specimens differ little in morphological
features or in counts (Table 2); (2) ripe indi-
viduals of both sexes occur in both color
forms; and (3), though the two color forms
overlap in size ranges, the plain brown form
is represented only by specimens 47 to 70 mm.
in standard length, whereas black and white
specimens range from 17 to 57 mm. In life
both forms may be seen over the same coral
head. Presumably the brown form represents
an ontogenetic color change that occurs after
maturity has been attained.

Chromis vanderbilti (Fowler)
1 spec., 35 mm., 1951.

This specimen differs from Hawaiian and
Wake Island material in lacking the black on
the lower caudal lobe. There appear to be no
other differences. Dorsal XII, 11; anal II, 11,
the anterior two-thirds black, becoming
abruptly light posteriorly.

Dascyllus albisella Gill
12 specs. 43–88 mm., 1951; 2 specs., 69–75
mm., Brock, 1948.

Though no specimens of *Dascyllus trima-
culatus* are readily available, the Hawaiian form
seems to differ, among other features, in hav-
ing more dorsal and anal soft rays. The
present (1951) specimens agree with the Ha-
waiian form in having 15 dorsal soft rays in
two specimens and 16 in ten, 14 soft rays in
the anal of one specimen, and 15 in the anal
of eleven.

*Dascyllus marginatus (Rüppell)
Halstead and Bunker, 1954, 4 specs.

Plectroglyphidodon johnstonianus
Fowler
8 specs., 27–80 mm., 1951. Fowler and Ball,
1925, 1 spec. As *Abudefduf johnstonianus*, Hal-
stead and Bunker, 1954, 1 spec.

Lips plicate; dorsal XII, 18; anal II, 16
or 17.

LABRIDAE

*Bodianus bilunulatus (Lacepède)
As *Harpe bilunulata*, Smith and Swain,
1882, 1 spec.

Cheilinus rhodochrous Günther
3 specs., 146–205 mm., 1951. Halstead and
Bunker, 1954, 5 specs. As *Cheilinus digramma*,
Smith and Swain, 1882, 3 specs., and Fowler
and Ball, 1925, 1 spec.

The 1951 specimens have the elongate
head, white band on the caudal peduncle, and
IX dorsal spines that seem to characterize this
species. No black lines radiating downward
from eye.

Epibulus insidiator (Pallas)
9 specs., 73–255 mm., 1951. Fowler and
Ball, 1925, 2 specs.; Halstead and Bunker,
1954, 4 specs.

Lower jaw extending backward to isthmus.

*Gomphosus tricolor Quoy and Gaimard
Fowler and Ball, 1925, 2 specs.

Gomphosus varius Lacepède
16 specs., 27–106 mm., 1951; 4 specs., 27–
89 mm., Brock, 1948.

A dark stripe through eye; vertical fins
dark.

Halichoeres ornatissimus (Garrett)
1 spec., 58 mm., 1951. Fowler and Ball,
1925, 2 specs., these reexamined.

These specimens all have the characteristic
dark mark just behind the eye.

Novaculichthys taeniourus (Lacepède)
1 spec., 119 mm., 1951.

Only four lines radiating out from the eye.

Pseudocheilinus sp.
12 specs., 30–55 mm., 2 specs., 40–46 mm.,
Brock, 1948.

First dorsal rays usually produced into
elongate filaments; two longitudinal scale
rows on cheek below eye; three or four black
longitudinal lines along upper sides; back-
ground color of body bluish; 16 rays in the

pectoral counting the splint above; no black dot on the caudal peduncle above.

This species will be described elsewhere by Dr. L. P. Schultz.

*Pseudocheilinus hexataenia (Bleeker)

Fowler and Ball, 1925, 6 specs. This record undoubtedly refers to either *Pseudocheilinus* sp. or *P. octotaenia*.

Pseudocheilinus octotaenia (Jenkins)

2 specs., 73 and 85 mm., 1951; 1 spec., 76 mm., Brock, 1948.

First dorsal rays not longer than those of the middle of the fin; three longitudinal rows of scales on cheek below eye; six to eight black longitudinal lines on sides, the lowermost well below the middle of the body; 14 rays in the pectoral fin counting the splint-like ray above.

Stethojulis axillaris (Quoy and Gaimard)

17 specs., 30–71 mm., 1951; 1 spec., 82 mm., Brock, 1948.

One or more black dots along the middle of the caudal peduncle.

Thalassoma ballieui (Vaillant and Sauvage)

Fowler and Ball, 1925, 1 spec. As *Julis verticalis* Smith and Swain, 1882, 1 spec.

Fowler and Ball's specimen has been reexamined. Though in poor condition, it does show the concentration of vertical markings on the scales on the caudal peduncle.

Thalassoma duperrey (Quoy and Gaimard)

16 specs., 55–162 mm., 1951; 1 spec., 146 mm., Brock, 1948. Halstead and Bunker, 1954, 1 spec. As *Julis clepsydralis* Smith and Swain, 1882, 1 spec.

A distinct light brown cross band through shoulder region in life, the fish becoming plain dark in preservative without marks except often for a dark mark on the upper edge of the pectoral base.

Thalassoma lutescens (Lay and Bennett)

5 specs., 53–116 mm., 1951. As *Thalassoma aneitense*, Fowler and Ball, 1925, 1 spec.

This species, of greenish yellow coloration in life, agrees well with Jordan and Evermann's plate (1905, pl. 41, as *T. aneitense*) except that each scale has an indistinct vertical stripe. However, there seems to be no way besides color by which to distinguish these specimens from *T. duperrey*, and it might prove difficult to refute the view that they simply represent a color variant of *T. duperrey* (similar to the yellow phase of *Epibulus insidiator*). The absence of canine teeth given by Jordan and Evermann (*op. cit.*) is valueless. Johnston specimens of *T. lutescens* have canine teeth exactly as in *T. duperrey*.

Thalassoma purpureum (Forskål)

Fowler and Ball, 1925, 1 spec.

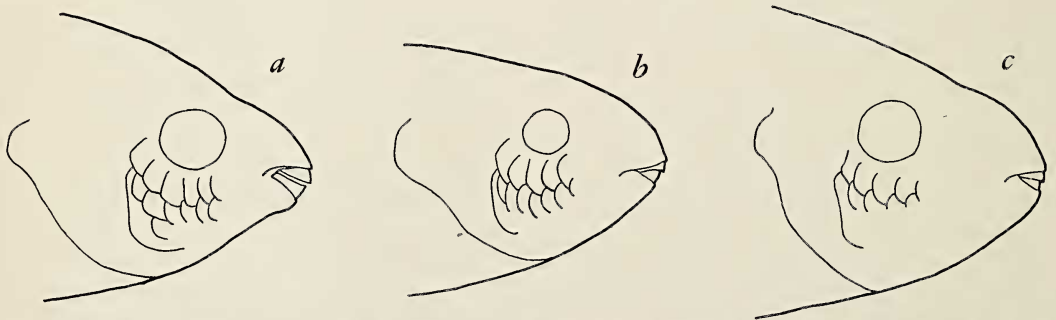This specimen has been reexamined. It has the broad band, branching below, extending

FIG. 2. Heads of species of *Scarus*. *a, Scarus dubius,* from a specimen 4¼ inches in total length with the mouth slightly open and the lips somewhat retracted; *b, Scarus sordidus,* from a 5¾-inch specimen; *c, Scarus perspicillatus,* from a 5½-inch specimen.

down and back from the eye typical of the species.

Thalassoma quinquevittata (Lay and Bennett)

10 specs., 48–110 mm., 1951; 1 spec., 62 mm., Brock, 1948.

Distance from tip of snout to origin of dorsal less than distance from tip of snout to origin of pelvics; a dark band around chin in adults; several dark marks along dorsal base in young.

SCARIDAE

Calotomus sandvicensis (Cuvier and Valenciennes)

7 specs., 90–235 mm., 1951.

The species of *Calotomus*, like those of *Scarus* (see below), are badly confused, and this must be considered a tentative identification.

Genus SCARUS

The present classification of the species of central Pacific parrot fishes is a mess. However, the group is in the process of being monographed (Schultz, ms.). In view of this the aims of the present account are quite limited. They comprise an attempt to separate what seem to be the three commonest species of the genus *Scarus* in Hawaiian waters (which happen to be the three species taken at Johnston) and to see to what extent the green and brown color phases of these species are correlated with sexual differentiation and maturity.

KEY TO THE SPECIES OF *Scarus* COLLECTED AT JOHNSTON ISLAND

1a. Lower (horizontal) limb of preopercular border relatively little developed (Fig. 2b, c), the length of its free edge (measured to the point at which the border runs vertically) less than the distance from its most anterior point to the midventral line; upper tooth plate never completely covered by the upper lip; pectoral rays usually 14 (not counting the small splint at the top); outline of the border of pelvic fins usually rounded; outer caudal rays never prolonged; canine teeth at the corners of the upper tooth plate, if present, low and knob like . . . 2

1b. Lower limb of preopercular border relatively well developed (Fig. 2a), its length equal to or greater than the distance from its most anterior point to the midventral line; upper tooth plate, when retracted, completely covered by the upper lip; pectoral rays 13 (14 in one out of 14 specimens); pelvic outlines usually pointed between the 1st and 2nd soft rays; caudal truncate in specimens up to 5 inches in total length (Fig. 3a, b), lunate in larger specimens (Fig. 3c) and usually with the outer rays prolonged in fishes between 8.5 inches and the maximum size attained (which is about 12 inches); adults usually with 1 to 3 conspicuous, conical, pointed canines at either side of the upper tooth plate. Two complete scale rows on cheek with sometimes a third incomplete row below (Fig. 2a); head of moderate size, less than the greatest depth of body in specimens over 6 inches long . . . . dubius

2a. Lower of the two scale rows on cheek, if present, incomplete, consisting of 1 to 3 scales; head relatively smaller, its length considerably less than the greatest body depth; attains at least 2 feet in length . . . . perspicillatus

2b. Lower of the two scale rows on cheek about as long as the upper, consisting of 5 to 7 scales; head relatively large and bullet shaped, its length about equal to the greatest depth of body; apparently does not reach a length of over 1 foot . . . . sordidus

Scarus dubius (Bennett)

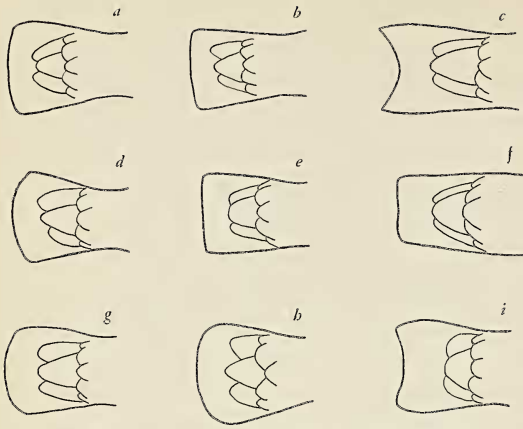13 specs., 39–162 mm., 1951 (brown form). As *Scarus brunneus*, Halstead and Bunker, 1954, 1 spec.

FIG. 3. Caudal fin outlines of *Scarus*. *a–c, Scarus dubius, a,* 2¾ inches in total length, *b,* 4¼ inches, *c,* 7¾ inches; *d–f, Scarus sordidus, d,* 3½ inches, *e,* 5¾ inches, *f,* 7 inches; *g–i, Scarus perspicillatus, g,* 2¾ inches, *h,* 5½ inches, *i,* 12¾ inches.

The rather extensive forward projection of the free preopercular border (Fig. 2*a*) is perhaps the most reliable way of distinguishing the species here tentatively identified as *S. dubius* from the other two species of *Scarus* dealt with here. The following distinguishing features, though helpful, appear to be less reliable. The pectoral rays are usually 13 instead of 14. When the jaws are retracted and the lips are in normal position, the upper lip extends down as a flap over the whole of the upper tooth plate; however, if the jaws are incompletely retracted (even though they may be partially closed as in Fig. 2*a*) or if the lips have been pushed back, the upper tooth plate may protrude. In the other two species the lips never cover the tooth plates except in very small specimens (less than 3 inches in total length). The two, more or less complete scale rows on the cheek will separate *S. dubius* from *S. perspicillatus* but not from *S. sordidus*. Certain features that change with growth are useful in separating *S. dubius* from the other two species if specimens of the same size are compared. Thus *S. dubius* develops a lunate caudal at a length of 7 inches in total length, whereas *S. perspicillatus* does not have a lunate caudal at sizes below 12 inches and *S. sordidus*

apparently never does have a lunate caudal. Again, *S. dubius* at a length of perhaps 7 inches usually develops one or two outwardly projecting canines at each corner of the upper jaw, but the other two species apparently never develop these beyond the stage of small, rounded tubercles.

Among the Hawaiian species of *Scarus* for which accounts are given by Jordan and Evermann (1905) the brown form here called *S. dubius* appears to have been included three times: as *Callyodon brunneus* (p. 349), *C. dubius* (p. 350), and as *C. bennetti* (p. 352). These, except for *C. brunneus*, differ in certain details from the form at hand. The major differences judging from Jordan and Evermann's accounts, are as follows: *Callyodon dubius* is said to have 14 pectoral rays; the pectoral count of the present specimens is usually 13. *C. bennetti* is figured with a rounded caudal (but this may be due to the small size of the specimen), the lips are said not to cover the upper jaw, and there are white lines along the scale rows of the lower sides (I have yet to see such markings). Though it is quite possible that more than one species is represented in the above group, a reexamination of Jordan and Evermann's material would be necessary to determine this. Of the three names, *S. dubius* (Bennett) is the oldest. Bennett's original description (1828: 828; type locality Oahu) is very sketchy. However, Günther has redescribed the type, along with other specimens, in two places (1862: 229; 1909: 313). In both of these redescriptions Günther mentions the presence of two scales in a row below the other two cheek rows. The species here dealt with is the only unspotted, brown Hawaiian *Scarus* known to me in which this third row ever occurs.

Scarus dubius apparently does not reach a large size. The largest brown specimen from Johnston is about 8 inches in total length. The largest specimen mentioned in Jordan and Evermann's accounts of *Callyodon brunneus, dubius,* and *bennetti* is 9.5 inches.

Of the five individuals more than 6 inches long from Johnston two, 6.4 and 8 inches long, are mature or maturing females. The ovaries are elongate, paired organs without sharp edges and contain small elongate eggs. The three other specimens, 7 to 7.4 inches in total length, contain in the ovarian position and behind the liver, flat, sharp-edged organs. The extent to which these structures are developed in the three individuals varies greatly. At one extreme they are small and leaf like. At the other they are somewhat larger than the largest ovary in the females mentioned above, rather thick, and overlap the intestines at the sides, above, and behind. These large structures must, I think, be identified as ripe testes.

The brown *Scarus dubius*, like the other two species to be dealt with, seems to have a green counterpart. Before discussing this, it seems advisable to say something about green parrot fishes in general based on experience with the scarids in Hawaii and elsewhere. Young parrot fishes, up to about 2 inches in length, are frequently, perhaps always, a plain light green color. These gradually become brownish with growth and I have never seen a green scarid between 3 inches and about 7 inches long. Green parrot fishes (more than 7 inches long) invariably have adult characteristics. In all the three species dealt with here, the size of the green counterpart is comparable to or somewhat larger than the mature brown form. Thus the green counterparts of small brown forms, e.g., *S. dubius* and *S. sordidus*, are always relatively small while those of large brown forms, e.g., *S. ahula* (=*perspicillatus*), are always relatively large. I have never seen a female green scarid, though, as just noted, some brown specimens appear to be adult males. Finally, green parrot fishes seem to be relatively rare as compared with brown individuals, though the distinctiveness in the color markings of the green as contrasted with brown forms has led to the description of numerous green species.

The green counterpart of *S. dubius* is rep-resented in the University of Hawaii collections by four specimens 170 to 190 mm. in total length that died in the Honolulu Aquarium and by one taken at Kailua, Kona, Hawaii. The aquarium specimens are so badly damaged that an exact correspondence in many morphological characters between them and the brown *S. dubius* could not be checked. They do agree in having two scale rows on the cheek, a relatively long horizontal limb to the free preopercular border, 13 pectoral rays, pointed ventrals, and a rather small head. In only two of the four could gonads be found. In these there were relatively small, elongate, sharp edged organs without eggs that must be considered testes.

The 12 inch Kailua specimen is in better condition and hence of greater interest. It is an unripe male; I can only find a testis on the left side. The description of the morphological characters given for the adult brown *S. dubius* fits this specimen completely. The mouth is closed and the upper lip projects forward as a flap over the whole upper tooth plate. The pectoral rays are 13 on each side and there are two complete rows of scales on the cheek. There is a single outwardly-projecting canine on each side of the upper jaw. The caudal is lunate and the outermost soft pelvic ray extends well beyond the others.

Jordan and Evermann (*op. cit.*) recognize six green species of *Scarus* from the Hawaiian islands: "*Callyodon*" *perspicillatus* (p. 347), *C. jenkinsi* (p. 353), *C. gilberti* (p. 354), *C. formosus* (p. 355), *C. lauia* (p. 355), and *C. bataviensis* (p. 356). Of these *Scarus perspicillatus* has the lower row of cheek scales incomplete, and Brock and Yamaguchi (1954: 154) have already demonstrated that it is the adult male of "*S. ahula*." The color description and plate given by Jordan and Evermann for *Scarus lauia* is decidedly dissimilar to that of the specimen at hand and seems to represent an entirely different species. As for the remaining forms: *S. jenkinsi*, *S. gilberti*, *S. formosus*, and *S. bataviensis*, there is nothing in Jordan and Evermann to indicate that any or all of them are

not the species represented by the Kailua specimen. I can see nothing to indicate that this in turn is not an old male of the brown form represented by S. *dubius*. Since S. *dubius* is the oldest name to be applied in either the brown or the green complex dealt with, it may be, at least provisionally, used for this species.

Scarus sordidus Forskål

78 specs., 57–222 mm., 1951 (75 brown, 3 green); 5 specs., 115–175 mm., Brock, 1948. Fowler and Ball, 1925, 2 specs.

This species does not seem to be among those described by Jordan and Evermann and the identification for it was kindly provided by Dr. L. P. Schultz of the U. S. National Museum. It has a characteristic bullet-shaped head and usually has the tooth plates protruding well beyond the lips. These tooth plates are of a dirty, greenish tinge in alcohol. The caudal of this species is rounded in small specimens but truncate in fishes 5.5 inches in total length and larger. It is the most elongate of the three species, and the eye is smaller than in the other two species at the same size. The anal rays are somewhat shorter than in S. *perspicillatus* (longest anal ray contained 1.85–2.34 in anal base of S. *sordidus*, 1.44–1.98 in S. *perspicillatus*). This form often has a white band on the caudal peduncle and there is frequently a black spot in the middle of the band.

It seems to be the commonest scarid at Johnston and not at all infrequent around Oahu. The largest specimen of this brown form taken is about 9 inches long. Most of the specimens more than 5 inches long are mature females with eggs. The ovaries are similar to those of S. *dubius* and are paired in the single specimen checked. Again certain specimens contain the asymetrical, liver-like structure found in the brown form of S. *dubius*. Of a dozen brown specimens checked, one 4.5 inches long was an immature. The rest are larger, the largest being 8.3 inches in total length. Of these, 8 are mature females, and 3

have a large, flattish liver-like organ in the ovarian position. The size of this flattish organ, when present is, in 2 out of the 3 specimens, larger than the largest ovary. This seems peculiar if it is a testis, but repeated attempts to find eggs in it have failed. The facts that the liver is also present in these specimens, that there are no other gonad-like structures along with it, and that it contains no eggs seems to leave little alternative to identifying the structure as a testis despite its size.

Three green specimens, 10.2 to 10.5 inches in total length, were taken with the brown form from Johnston described above. These all duplicate the brown form of S. *sordidus* in morphological characters, e.g., the long head with greatly protruding, greenish tooth plates, the two complete scale rows on the cheek, rounded pelvics, etc. Though the outer caudal rays extend somewhat beyond the inner ones they are not produced as in the green form of S. *dubius*. There are from 0 to 3 small knobs at the sides of the upper jaw; these do not project outward to nearly the extent that they do in adult S. *dubius*. In all of these there is a flat organ on the right side, but in one of the three it does not seem to occur on the left. In this one the organ on the right side is quite small, in the other two of moderate size, considerably smaller than the same organ at its maximum development in the smaller brown form. I think two of the three green specimens may be considered ripe or ripening males and the third an unripe male. In color, these specimens, though faded, differ considerably from the green form of S. *dubius*. The pelvic and caudal coloration is quite plain and that on the head seems to have consisted of broad, indefinite dark bars around the mouth and behind the eye.

Scarus perspicillatus (Steindachner)

5 specs., 72–290 mm., 1951 (4 brown, 1 green). Smith and Swain, 1882, 1 spec.; Halstead and Bunker, 1954, 12 specs. As *Callyodon perspicillatus* Fowler and Ball, 1925, 4

specs. As *Callyodon ahula* Fowler and Ball, 1925, 2 specs.

Since Brock and Yamaguchi have already demonstrated (1954) that the green *S. perspicillatus* is the adult male of the brown *S. ahula*, and since my material adds little to this information, the account of this species may be cut short. Only five specimens of this species were taken at Johnston, four brown and one green. The green specimen, 14 inches in total length, is a ripe male with very large, paired testes. Of the brown form, specimens 4.5 to 9.5 inches in total length are immatures; the other, 14 inches long, is a ripe or ripening female. The large female differs from the ripe male (and from brown specimens of a similar size from Hawaii) in the considerably greater depth of body, but I can see no other characters on which to separate them.

Additional species of *Scarus* recorded from Johnston are:

*Scarus cyanogrammus (Jordan and Seale)
    Halstead and Bunker, 1954, 1 spec.

*Scarus duperrey (Quoy and Gaimard)
    Halstead and Bunker, 1954, 1 spec.

*Scarus erythrodon Cuvier and
    Valenciennes
    As *Callyodon erythrodon*, Fowler and Ball, 1925, 4 specs.

*Scarus forsteri Valenciennes
    Halstead and Bunker, 1954, 1 spec.

CHAETODONTIDAE

Centropyge flammeus Woods and Schultz
    4 specs., 70–81 mm., 1951. Woods and Schultz, in Schultz, *et al.*, 1953, 6 specs. As *Holacanthus loriculus*, Fowler and Ball, 1925, 1 spec.

*Centropyge nigriocellus Woods and
    Schultz
    Woods and Schultz, in Schultz, *et al.*, 1953, 1 spec.

Chaetodon auriga Forskål
    14 specs., 112–145 mm., 1951; 1 spec., 117

mm., Schaefer, 1948. Halstead and Bunker, 1954, 7 specs. As *Chaetodon setifer*, Smith and Swain, 1882, 1 spec. and Fowler and Ball, 1925, 5 specs.

Chaetodon citrinellus Cuvier
    5 specs., 92–100 mm., 1951. Halstead and Bunker, 1954, 1 spec.

Chaetodon ephippium Cuvier
    2 specs., 124 and 158 mm., 1951. Fowler and Ball, 1925, 1 spec.; Halstead and Bunker, 1954, 2 specs.

Chaetodon multicinctus (Garrett)
    3 specs., 86–89 mm., 1951. As *Chaetodon punctatofasciatus*, Fowler and Ball, 1925, 3 specs. and Halstead and Bunker, 1954, 2 specs.
    This species is dealt with briefly in section 2.

Chaetodon ornatissimus Solander
    4 specs., 110–147 mm., 1951. Fowler and Ball, 1925, 3 specs.; Halstead and Bunker, 1954, 4 specs.

Chaetodon quadrimaculatus Gray
    2 specs., 108 and 108 mm., 1951. Fowler and Ball, 1925, 3 specs.

Chaetodon trifasciatus Mungo Park
    Fowler and Ball, 1925, 5 specs. Determination checked.

Chaetodon unimaculatus Bloch
    3 specs., 82–88 mm., 1951; 1 spec., 41 mm., Brock, 1948. Fowler and Ball, 1925, 6 specs.

*Megaprotodon strigangulus (Gmelin)
    Halstead and Bunker, 1954, 1 spec.

ZANCLIDAE

Zanclus cornutus Cuvier
    1 spec., 98 mm., 1951. Halstead and Bunker, 1954, 1 spec. As *Zanclus canescens*, Fowler and Ball, 1925, 2 specs.

ACANTHURIDAE

Acanthurus achilles Shaw
    18 specs., 114–210 mm., 1951. Halstead

and Bunker, 1954, 4 specs. As *Hepatus achilles*, Fowler and Ball, 1925, 3 specs.

Acanthurus elongatus (Lacepède)

54 specs., 80–126 mm., 1951. Halstead and Bunker, 1954, 13 specs. As *Hepatus lineolatus*, Fowler and Ball, 1925, 5 specs.

A small dark spot at the base of the last dorsal and anal rays.

Acanthurus olivaceus Schneider

1 spec., 200 mm., 1951. Halstead and Bunker, 1954, 6 specs. As *Hepatus olivaceus*, Fowler and Ball, 1925, 1 spec.

Fowler and Ball record 3 specimens of *Hepatus nigricans* from Johnston; one of these is in the Bishop Museum and is *Acanthurus olivaceus*.

Acanthurus sandvicensis Streets

21 specs., 63–127 mm., 1951. As *Acanthurus triostegus*, Smith and Swain, 1882, 2 specs. and Halstead and Bunker, 1954, 5 specs.; as *Hepatus sandvicensis*, Fowler and Ball, 1925, 7 specs.

This species will be treated in section 2.

*Ctenochaetus striatus (Quoy and Gaimard)

Halstead and Bunker, 1954, 7 specs.

Ctenochaetus strigosus (Bennett)

11 specs., 72–106 mm., 1951; 1 spec., 80 mm., Brock, 1948. Fowler and Ball, 1925, 1 spec.

These specimens are included in Randall's report on the genus which is in press.

Naso lituratus (Schneider)

5 specs., 152–210 mm., 1951. Halstead and Bunker, 1954, 7 specs. As *Naseus lituratus*, Smith and Swain, 1882, 2 specs.; as *Acanthurus lituratus*, Fowler and Ball, 1925, 4 specs.

Zebrasoma flavescens (Bennett)

1 spec., 54 mm., 1951. Fowler and Ball, 1925, 3 specs.; Halstead and Bunker, 1954, 1 spec.

Plain yellow in color.

ELEOTRIDAE

Eviota viridis (Waite)

Fowler and Ball, 1925, 3 specs.

These specimens have been reexamined, but are in too poor condition to provide a definite identification.

GOBIIDAE

*Bathygobius fuscus Rüppell

Fowler and Ball, 1925, 4 specs.

There seems no reason to doubt the original determination.

Gnatholepis anjerensis (Bleeker)

5 specs., 19–34 mm., 1951.

Tongue strongly bilobed; anal with 11 soft rays in all 5 specimens.

Zonogobius farcimen (Jordan and Evermann)

5 specs., 16–22 mm., 1951.

These specimens agree well with the description and figure of this species by Jordan and Evermann (1905).

BLENNIIDAE

Cirripectus variolosus (Valenciennes)

52 specs., 24–63 mm., 1951; 2 specs., 55 and 59 mm., Brock, 1948. As *Rupiscartes variolosus*, Fowler and Ball, 1925, 22 specs.

Body plain; nuchal cirri totaling 36 in one specimen; first dorsal rays elongate.

Exallias brevis (Kner)

1 spec., 46 mm., Brock, 1948.

A broad fleshy flap on either side of the chin; scattered reddish spots on the head, body, and fins.

Salarias gibbifrons (Quoy and Gaimard)

17 specs., 23–73 mm., 1951. As *Rupiscartes gibbifrons*, Fowler and Ball, 1925, 1 spec.

Long, simple, slender cirri over eye; middle of eye about over front of upper jaw; a spot between the first two dorsal spines.

BROTULIDAE

Brotula townsendi Fowler

1 spec., 127 mm., 1951.

This specimen has been reported on previously (Gosline, 1953).

MUGILIDAE

Neomyxus chaptalii (Eydoux and Souleyet)
    1 spec., 286 mm., 1951. Fowler and Ball, 1925, 5 specs.
    Forty-four scales in a longitudinal series.

SPHYRAENIDAE

***Sphyraena japonica** (Cuvier)
    Fowler and Ball, 1925, 3 specs.

POLYNEMIDAE

***Polydactylus sexfilis** (Cuvier and
    Valenciennes)
    As *Polynemus kuru*, Smith and Swain, 1882, 1 spec.

SCORPAENIDAE

Scorpaenids seem to be rare around Johnston, and the only two species taken are the two that are perhaps commonest around Hawaii. They are not difficult to separate but they have been badly confused. Nomenclatorially the difficulty starts at the generic level. Jordan and Evermann (1905) have placed the two in *Sebastapistes*. Schultz (1943), for reasons which are not clear, divides the members of *Sebastapistes* between *Scorpaenopsis* and *Scorpaena*. Matsubara (1943), who will be followed here, places all of *Sebastapistes* back under *Scorpaena*.

At the specific level a nomenclatorial problem also arises. The oldest name for any Hawaiian species is *Scorpaena asperella* Bennett (1828). The description of this species, based on a single specimen 2 inches long, gives almost no morphological characters of any value, and the coloration does not agree very well with anything subsequently found in the Hawaiian Islands. The type, according to Günther (1873: 80), has been lost. The name *Scorpaena asperella* has been applied in various ways. Günther (1860: 107) considered the species unrecognizable. Jordan and Ever-

mann (1905) thought that the description applied to some Hawaiian species that they did not have. This seems rather unlikely, for of the 11 Hawaiian species described by Bennett 9 of the names have subsequently been identified among the most common of small inshore fishes and the other 2 have never been identified very satisfactorily with anything. One suspects that the difficulty with these 2 lies not in the rarity of the species described but in the nature of Bennett's descriptions. In 1943 Schultz (p. 172) applied the name to a species from Samoa.

I have repeatedly compared Bennett's description with small scorpaenids from Hawaii and can only conclude that it checks about as well (or as badly) with one as with another. Under the circumstances it seems best to follow Günther's usage in considering the name unrecognizable.

The following tabulation of characteristics will serve to distinguish the two species of *Scorpaena* collected at Johnston:

Eight spines on the top of the head above and behind the orbital rim, the front four in a transverse row; pectoral base without scaly sheath; cheek and opercle naked; pectoral with 4 branched rays; suborbital with a single blunt, backwardly projecting knob; no distinct, small dark spots; a black blotch usually present on the posterior part of the spinous dorsal in specimens more than 3 inches long; last dorsal ray attached for most of its length to the caudal peduncle by means of a membrane........
..........................S. **ballieui**

Six spines on the top of the head above and behind the orbital rim; pectoral with a scaly sheath at base that extends well out onto the pectoral fin; cheek and opercle scaled; pectoral with 5 branched rays; suborbital with two divergent, backwardly projecting points; small, distinct dark spots on and below the base of the dorsal fin, on the head, and in the pectoral axil; no black

blotch on the posterior part of the spinous dorsal; last dorsal ray attached to the caudal peduncle for less than half its length.....
.........................S. coniorta

Five species of *Sebastapistes* from Hawaii are recognized by Jordan and Evermann (1905: 455–460), and a sixth is described from deeper water by Gilbert (1905: 627). Of these *S. asperella*, as noted above, must apparently be considered unidentifiable. Of the others, *S. coniorta* seems to apply to the scaled-cheek species. Judging from Jordan and Evermann's descriptions, *S. balieui*, *S. corallicola*, and probably *S. galactacma* belong with the naked-cheeked species. *S. coloratus* appears to represent a third species.

At present it seems best to designate the two Johnston species as *Scorpaena ballieui* Sauvage and *S. coniorta* (Jenkins). Other related species have been described from elsewhere in the tropical Indo-Pacific, but in the absence of comparative material it is impossible to determine which of these are the same as the two Johnston species and which are different.

Scorpaena ballieui Sauvage
1 spec., 23 mm., 1951.

Scorpaena coniorta (Jenkins)
1 spec., 51 mm., 1951.

BOTHIDAE

Bothus mancus (Broussonet)
1 spec., 160 mm., 1951. Halstead and Bunker, 1954, 2 specs. As *Platophrys mancus*, Smith and Swain, 1882, 1 spec. and Fowler and Ball, 1925, 3 specs.
Dorsal 96; anal 78.

ECHENEIDAE

Remora remora (Linnaeus)
1 spec., 67 mm. from shark taken outside reef.
Pelvic fins with their inner rays attached to the abdomen for most of their length; laminae 17; lower jaw greatly exceeding upper in length.

BALISTIDAE

Melichthys buniva (Lacepède)
9 specs., 155–185 mm., 1951. Fowler and Ball, 1925, 3 specs. As *Balistes buniva*, Smith and Swain, 1882, 3 specs.
Dorsal and anal black with a narrow blue line at base. A very common species, which seemed to be thriving on the garbage periodically dumped into the lagoon at the time we were there.

*Melichthys ringens (Osbeck)
Halstead and Bunker, 1954, 11 specs.

Melichthys vidua (Solander)
1 spec., 150 mm., 1951. Halstead and Bunker, 1954, 2 specs. As *Balistes vidua*, Fowler and Ball, 1925, 2 specs.
Dorsal and anal light except for the narrow dark borders. Fraser-Brunner's placement (1935: 662) of this species in the genus *Melichthys* seems questionable.

Rhinecanthus aculeatus (Linnaeus)
Halstead and Bunker, 1954, 3 specs. As *Balistes aculeatus*, Smith and Swain, 1882, 2 specs. and Fowler and Ball, 1925, 1 spec. (this record checked).
Three longitudinal rows of black spinelets on the caudal peduncle.

MONACANTHIDAE

*Amanses carolae (Jordan and McGregor)
Halstead and Bunker, 1954, 2 specs.

Amanses sandwichiensis (Quoy and Gaimard)
3 specs., 140–270 mm., 1951. Halstead and Bunker, 1954, 1 spec. As *Monacanthus sandwichiensis*, Fowler and Ball, 1925, 1 spec.
The 140 mm. specimen has no spines on the caudal peduncle; the two larger (190 and 270 mm.) have 4 forwardly projecting spines in two rows on each side.

Pervagor melanocephalus (Bleeker)
3 specs., 82–106 mm., 1951. As *Monacanthus melanocephalus*, Fowler and Ball, 1925, 4 specs.

Dorsal rays 32 in one specimen.

OSTRACIONTIDAE

*Kentrocarpus hexagonus (Thunberg)
  Halstead and Bunker, 1954, 1 spec.

*Ostracion cubicus Linnaeus
  Halstead and Bunker, 1954, 1 spec.

Ostracion lentiginosum Schneider
  15 specs., 76–126 mm., 1951. Fowler and Ball, 1925, 3 specs. As *Ostracion punctatum*, Smith and Swain, 1882, 1 spec.

*Ostracion meleagris Shaw
  Halstead and Bunker, 1954, 9 specs.

Ostracion solorensis Bleeker
  Fowler and Ball, 1925, 1 spec.
  This specimen has the upper sides with alternating brown and white stripes, the brown ones continuous but the white ones broken up into segments. Below the banded area the body is abruptly light. A very slight dorsal ridge just ahead of dorsal fin; ventro-lateral ridges expanded into laminae. Carapace closed over behind the dorsal and anal fins to form two horizontal laminae. Supraorbital ridges somewhat raised and rough. No spines anywhere.

TETRAODONTIDAE

Arothron meleagris (Lacepède)
  2 specs., 140 and 160 mm., 1951. Halstead and Bunker, 1954, 1 spec. As *Tetraodon meleagris*, Smith and Swain, 1882, 3 specs., Fowler and Ball, 1925, 4 specs.
  Head, body, and fins with small light spots on a dark ground. Outer portions of fins, except caudal, light.

CANTHIGASTERIDAE

Canthigaster jactator (Jenkins)
  3 specs., 40–64 mm., 1951; 1 spec., 52 mm., Brock, 1948. Halstead and Bunker, 1954, 1 spec.
  Round white spots on a dark ground.

DIODONTIDAE

*Diodon hystrix Linnaeus
  Smith and Swain, 1882, 1 spec.

SECTION 2. THE NATURE AND RELATIONSHIPS OF THE JOHNSTON ISLAND FISH FAUNA

Johnston Island is one of the more isolated of Pacific atolls. It is separated by some 450 miles of deep water from the nearest reef area, French Frigate Shoals in the Hawaiian chain to the north (see Fig. 1). To the south and east the nearest shoal water (Kingman Reef in the Line Islands) is about 700 miles away, whereas the closest land to the west is in the Marshalls perhaps 1300 miles distant.

The position of Johnston Island poses two principal questions for the zoogeographer: (1) to what extent does its isolation give rise to endemism, and (2) to what extent has Johnston acted as a stepping stone or filter bridge between the Hawaiian biota and that of the Line Islands to the south. An attempt to answer these two questions constitutes the present section of this paper.

Before proceeding it seems well to define certain terms that will be used here. "Central Pacific" will be employed in a zoogeographic sense to refer to a faunal area whose limits are unknown but which includes the Line, Phoenix, Gilbert, and Marshall islands but *not* Johnston and the Hawaiian chain. "Hawaiian" used zoogeographically will refer to the inshore marine fauna of the Hawaiian chain together with that of Johnston. "Hawaii" used geographically generally refers to the Hawaiian chain of islands, though the fact that the largest island in this chain is also called Hawaii is admittedly confusing.

The question of endemism among Johnston fishes is easily dealt with and dismissed. Only two species of Johnston fishes have not been taken elsewhere—*Centropyge nigriocellus* and *C. flammeus*. Neither of these is abundant at Johnston (the former is known only from one specimen), and it may well be that they merely

remain uncollected elsewhere. In a few other fishes the Johnston specimens seem somewhat aberrant but probably do not deserve recognition as separate species. The principal significance of this low degree of endemism at Johnston lies in the demonstration that for Pacific island fishes 450 miles of open water without strong current systems has not resulted in much differentiation.

The problem of evaluating Johnston as a filter bridge is far more complex. The present attack on it is divided into two facets. The first approaches the problem in terms of the relative strengths of the various components of the Johnston shallow-water fish fauna. The objective here is to obtain a general picture of the relationships of the fish fauna of Johnston Island. The second deals in greater detail with certain Johnston fishes that are represented by different geographic forms south of the island than occur to the north. Its objective is to trace, in so far as possible, individual migration routes.

Components of the Johnston Fish Fauna

For purposes of the faunal analysis that follows, certain families of fishes have been excluded for one reason or another. First, those fishes that are pelagic or semipelagic as adults are omitted. For these, Johnston may have no significance whatever as a way point, and to include them would only obscure the data. Groups excluded from consideration for this reason are the sharks and rays, the needle fishes, half-beaks, flying fishes, carangids, barracudas, tunas, remoras, and all fishes taken from over 100 feet of water. Second, the parrot fishes and scorpaenids have also been excluded, but for the reason that at the present time they are so confused taxonomically as to make species records worthless zoogeographically. Finally, the species recorded from Johnston by Halstead and Bunker (1954) only will not be considered as I have not been able to check their records. Fowler and Ball's (1925) species have, on the other hand, been included because, as already mentioned, material upon which their more questionable identifications were based have been reexamined. Following is the reduced list of Johnston species, upon which the following analysis is based.

SPECIES CONSIDERED IN THE ANALYSIS OF THE
JOHNSTON FISH FAUNA

Central Pacific Species Reaching Johnston but
Not Hawaii (Group B of Fig. 4)
Leptenchelys labialis
Muraenichthys gymnotus
Muraenichthys schultzei
Brachysomophis sauropsis
Myrichthys bleekeri
Echidna leucotaenia
Uropterygius polyspilus
Kuhlia marginata
Parupeneus barberinus
Abudefduf phoenixensis
Epibulus insidiator
Thalassoma quinquevittata
Pervagor melanocephalus
Ostracion solorensis

Species Endemic to Johnston (Group G of Fig. 4)
Centropyge flammeus
Centropyge nigriocellus

Hawaiian Species Reaching South to Johnston but
Not Beyond (Group E of Fig. 4)
Muraenichthys cookei
Gymnothorax eurostus
Uropterygius dentatus
Apogon menesemus
Apogon waikiki
Parupeneus multifasciatus
Cirrhitus alternatus
Chromis leucurus
Chromis vanderbilti
Dascyllus albisella
Halichoeres ornatissimus
Thalassoma ballieui
Thalassoma duperrey
Chaetodon multicinctus
Acanthurus sandvicensis
Zonogobius farcimen

Johnston Species Found Both in Hawaii and in the
Central Pacific (Group C of Fig. 4)
Saurida gracilis
Synodus binotatus
Conger noordziekii
Leiuranus semicinctus
Myrichthys maculosus
Schultzidia johnstonensis
Moringua macrochir
Anarchias allardicei
Anarchias cantonensis
Anarchias leucurus
Echidna polyzona
Echidna zebra

Gymnothorax gracilicauda
Gymnothorax meleagris
Gymnothorax moluccensis
Gymnothorax pictus
Gymnothorax undulatus
Rabula fuscomaculata
Uropterygius fuscoguttatus
Uropterygius tigrinus
Aulostomus chinensis
Fistularia petimba
Holocentrus tiere
Holocentrus microstomus
Holocentrus lacteoguttatus
Holocentrus sammara
Holocentrus spinifer
Holotrachys lima
Myripristis argyromus
Apogon erythrinus
Apogon snyderi
Pseudamiops gracilicauda
Pseudogramma polyacanthus
Priacanthus cruentatus
Kyphosus vaigiensis
Mulloidichthys auriflamma
Mulloidichthys samoensis
Parupeneus bifasciatus
Parupeneus chryserydros
Parupeneus pleurostigma
Paracirrhites bimacula
Abudefduf imparipennis
Abudefduf sordidus
Plectroglyphidodon johnstonianus
Bodianus bilunulatus
Cheilinus diagrammus
Cheilinus rhodochrous
Gomphosus tricolor
Gomphosus varius
Novaculichthys taeniourus
Pseudocheilinus sp.
Pseudocheilinus octotaenia
Stethojulis axillaris
Thalassoma lutescens
Thalassoma purpureum
Chaetodon auriga
Chaetodon citrinellus
Chaetodon ephippium
Chaetodon ornatissimus
Chaetodon quadrimaculatus
Chaetodon trifasciatus
Chaetodon unimaculatus
Zanclus cornutus
Acanthurus achilles
Acanthurus elongatus
Acanthurus olivaceus
Ctenochaetus strigosus
Naso lituratus
Zebrasoma flavescens
Bathygobius fuscus
Gnatholepis anjerensis
Exallias brevis
Cirripectus variolosus
Salarias gibbifrons
Brotula townsendi

Neomyxus chaptalii
Polydactylus sexfilis
Bothus mancus
Rhinecanthus aculeatus
Melichthys buniva
Melichthys vidua
Amanses sandwichiensis
Ostracion lentiginosum
Arothron meleagris
Canthigaster jactator
Diodon hystrix

For purposes of assessing the importance of Johnston as a filter bridge for species coming up from the south the following groupings have been made (see Fig. 4): (A) those fishes that never reached Johnston, (B) those that got to Johnston but no farther, (C) those that apparently passed through Johnston on the way from the Line Islands to Hawaii or vice versa, and (D) those that apparently by-passed Johnston. Similarly, the Hawaiian species may be divided into (F) those that never reached Johnston, (E) reached Johnston and stopped, (C) passed through Johnston, and (D) by-passed Johnston.

The stringency of the Johnstonian filtering effect on northbound and on southbound fishes will be shown by the relative strengths of each of the above categories (except D). An attempt to quantify each of these relative to one another is therefore made in Figure 4 by means of the widths of the columns. Widths of columns B, C, E, and G are based directly on the relative number of Johnston species in each of these categories in the list. Column D is given no width, because it is impossible to know how much of column D is represented but as yet uncollected at Johnston. Widths for A and F were estimated in a very simple and admittedly imperfect fashion, and indicate only rough magnitudes. Two shallow-water poison stations run at Palmyra, the nearest island to the south of Johnston, by Mr. J. E. King, et al., in approximately the same way as those made at Johnston yielded (among the same fish groups used here) 62 species of which 29 are not known from Johnston or Hawaii. Thus, the number of species in these two collections (and pre-

sumably in the Palmyra inshore fish fauna as a whole) that does not get north is calculated as 29/33 of the number that does. Consequently column A is assigned a width slightly less than the combined widths of B and C, which had been calculated previously. Similarly, the width of F is based on an inshore Oahu rotenone station from which 69 species in the same groups were collected. Of these, 17 do not get as far south as Johnston. Hence F is assigned a width about one third (actually 17/52) of the combined widths of C and E.

The fact that there are 16 Hawaiian species found at Johnston but not, apparently, farther south and 14 Central Pacific species that get to Johnston but not farther north indicates that at the present time Johnston is acting as a filter bridge for fishes passing in both directions. The nature of the filtering effect on northbound and on southbound species must now be considered.

Starting at the south, a very large component of the two poison stations run at Palmyra (29 of 52 species) is not known in Johnston or Hawaii. Two very striking members of this component are the genera *Lutjanus* and (except for a single species) *Epinephelus*. One immediately wonders if these fishes never got to the northern islands or whether they got there but have been unable to survive there because of unsuitable ecological conditions. If the latter were correct, one would suspect the colder water temperatures in the north to be either the direct or indirect cause of the unsuitability. There are certain indications that distance rather than water temperature has been the primary cause in preventing Central Pacific species from reaching Johnston and Hawaii. One of these is provided by the fishes of Japan. The southern Japanese Islands are separated by no such deep-water distances from tropical Pacific islands as Johnston is from Palmyra, but surface water temperatures in southern Japan are at least as cold as those of the Hawaiian Islands (Sverdrup, Johnson, and Fleming, 1946: charts II and III, and fig.

32B). Nevertheless, 15 species of *Epinephelus* (Tanaka, 1931: 26) and 14 species of *Lutjanus* (Kamohara, 1954: 114) are recorded from Japan. This suggests that the Hawaiian water temperatures would not be unsuitable for at least some species of *Lutjanus* and *Epinephelus*. An attempt to find an area separated from the tropical Pacific by a deep-water barrier as great as that isolating the Hawaiian Islands and Johnston leads to an examination of the tropical American data. Snodgrass and Heller (1905: 338) list some 13 species of inshore tropical Pacific species as occurring in the islands of the west coast of the Americas. Of these, none belong to the genera *Lutjanus* or *Epinephelus* or to any of the other species that are not represented at Johnston and Hawaii. To state this last matter positively, all 13 have representatives in the Hawaiian Islands today. These two straws in the wind indicate that the great diminution in species between Palmyra and Johnston is caused primarily by (deep-water) distance rather than by temperature. Such a distance effect could, of course, be either primary or secondary. If primary, the fishes themselves have been unable to get to Johnston; if secondary, the fishes may have been able to get there but the organisms they depend upon for a livelihood have not. Though there is no way of determining which of these two possibilities has been realized, it seems improbable that such unspecialized carnivorous genera as *Lutjanus* and *Epinephelus* would have found the food supply inadequate, had they arrived there.

Of those tropical fishes that have reached Johnston, the great majority seem to have passed on through to Hawaii. There are, however, 14 species that are not known north of Johnston. Some of these, e.g., *Epibulus insidiator*, are quite striking members of the tropical Pacific fauna, and it seems improbable that they should go unrecorded in the Hawaiian fauna if they exist there. One suspects that the reason they have not crossed the minor water gap between Johnston and
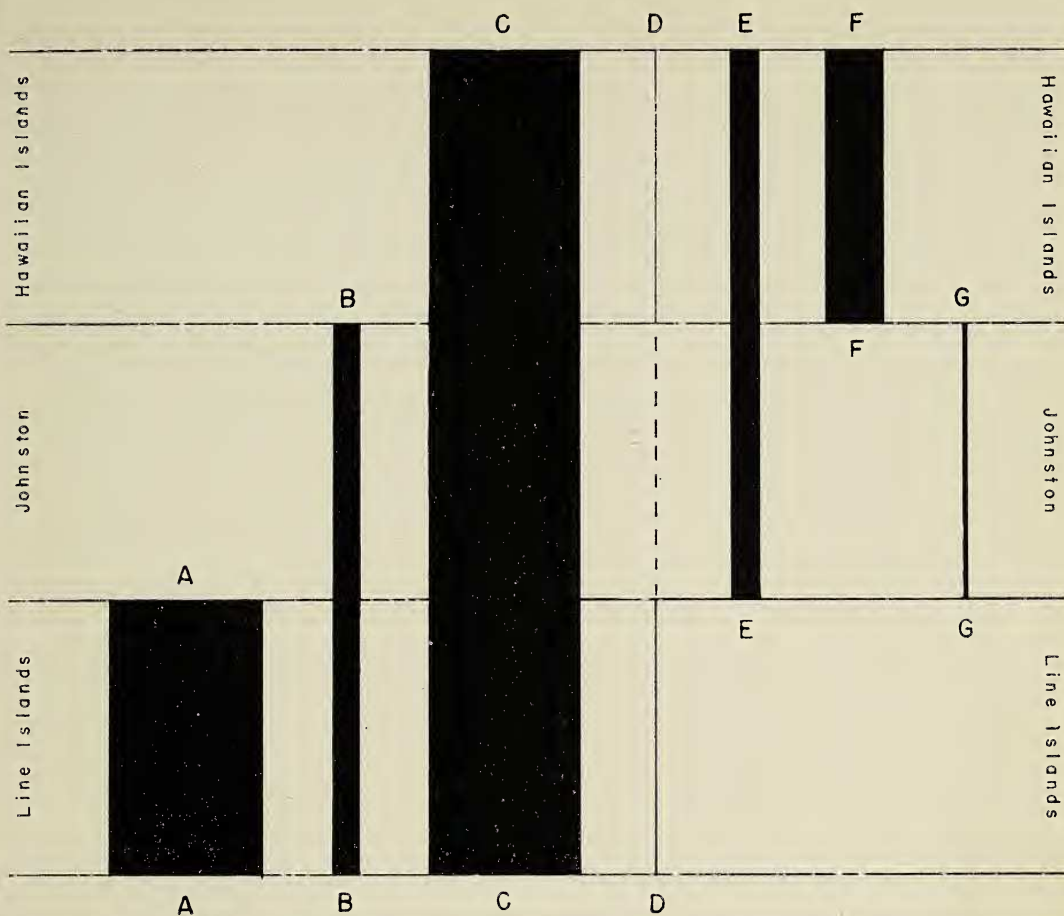
FIG. 4. Diagram of the zoogeographic components making up the inshore fish fauna of Johnston Island and the island chains nearest to Johnston. A, that portion of the Line Island fauna that does not reach Johnston or the Hawaiian Islands; B, that portion of the Line Island fauna that reaches to Johnston but not to the Hawaiian Islands; C, the component that is held in common by the Line Islands, Johnston, and the Hawaiian Islands; D, the component that is common to the Line and Hawaiian Islands but has not, up to now, been recorded from Johnston; E, that portion of the Hawaiian fauna that has reached Johnston but not farther south; F, the portion of the Hawaiian fauna that is restricted to the Hawaiian chain; and G, the component restricted to Johnston Island. Widths of the bars, except D, represent the relative strengths of the various components; for the way in which these widths were calculated, see text.

Hawaii after hurdling the major one between Palmyra and Johnston is that the ecological conditions in Hawaii are not suitable to them. This is of course merely a guess, but it may be noted that the Johnston coral reefs, made up as they are to a considerable extent of *Acropora*, would seem to form a quite different environment from the Hawaiian reefs, where *Acropora*, amongst other elements, is lacking. To bulwark this point further it may

be noted that certain rather prominent components of the tropical Pacific fauna that do reach Hawaii are rare there and apparently do not find the environment particularly suitable. In this category belong such species as *Gymnothorax pictus, Holocentrus microstomus, Thalassoma lutescens, Chaetodon citrinellus, Chaetodon ephippium, Pomacanthus imperator,* and *Acanthurus aliala.*

Summing up for the "northbound" fishes

it appears that: (1) close to a half of the Line Island inshore fish fauna does not occur in Johnston or Hawaii and that the principal reason for this is the great area of deep water between the northernmost Line Island reef and Johnston; (2) the majority of tropical Pacific fishes that have reached Johnston also occur in Hawaii; (3) the relatively few species of tropical Pacific fishes that are known from Johnston but not Hawaii may have reached but have not survived in the latter islands because of differences in ecological conditions between Johnston and the Hawaiian chain.

What may be termed the southbound fishes are now up for discussion. In the first place it must be noted that there is a very much smaller proportion of the Hawaiian inshore fishes restricted to the Hawaiian Islands (F of Fig. 4) than of tropical Pacific fishes that do not get north from the Line Islands (A of Fig. 4). Indeed, it is quite certain that there is a considerably smaller number of Hawaiian "endemics" with the potentialities for moving south than of tropical Pacific fishes that might move north. Of the former group a rather high percentage (though a low number of species) have reached Johnston. It is for this reason that Johnston is to be considered primarily as an outlier of the Hawaiian faunal region rather than as a part of the tropical Central Pacific fauna. The example drawn from the Palmyra and Hawaiian poison stations will bring out this point. In the Hawaiian rotenone station of 69 species, only 17 are restricted to Hawaii, but another 4 are restricted to Hawaii and Johnston. In the Palmyra poison stations of 62 species, 29 are not known north of Palmyra but only 1 is known from Palmyra and Johnston but not Hawaii. On the basis of these figures (fishes found both in Hawaii and Palmyra being excluded) the Johnston inshore fauna is 4/17 Hawaiian and 1/29 tropical Pacific. To what extent other Hawaiian endemics will turn up at Johnston remains to be seen.

Finally, it is necessary to say something of those fishes found today in Hawaii, Johnston,

and the tropical Pacific (C of Fig. 4). First, it seems certain that as more attention is given to the fishes in this category more of them will prove to show differentiation between the Hawaiian and Line Islands. Meanwhile there is no sure way of telling whether this group has moved north or south via Johnston. However, certain points regarding the hypothesis of Johnston as the original port of entry for the Hawaiian fauna may be mentioned. On the one hand, it is certain that the Hawaiian inshore fish fauna was ultimately derived from that of the tropical Pacific. Further, there is no island that could or does at the present time provide a better stepping stone between the Hawaiian chain and the tropical Pacific fauna. Finally it has been indicated above that Johnston does at the present time serve as a terminal point for at least some northward movement. On the other hand, the age of Johnston is unknown, and it may be that Johnston is younger than the Hawaiian fish fauna as we know it at present. If this were so, it would be far easier to explain why the following Hawaiian representatives of tropical Pacific forms rather than the latter forms themselves are present at Johnston: *Muraenichthys cookei, Gymnothorax eurostus, Cirrhitus alternatus, Chromis leucurus, Chaetodon multicinctus*, and *Acanthurus sandvicensis*. Because of these features it seems best not to make categorical statements as to whether (or how much of) the Hawaiian fish fauna did or did not originally enter via Johnston. It can, however, be stated that a more plausible port of entry has yet to be found.

Analysis of Individual Species

The individual species investigated here are Johnston fishes represented by different geographic variants in the Central Pacific and in the Hawaiian chain. They do not include all fishes in this category but only those for which sufficient information is available to be worth discussing. The following species complexes will be dealt with (in each pair the Hawaiian form is mentioned first): *Murae-*

nichthys cookei–laticaudata, *Gymnothorax eurostus–buroensis*, *Kuhlia sandvicensis–marginata*, *Cirrhitus alternatus–pinnulatus*, *Chaetodon multicinctus–punctato-fasciatus*, and *Acanthurus sandvicensis–triostegus*. A uniform treatment for all six species would be desirable in order to enable comparison of all six area by area. Unfortunately the availability of specimens makes this impossible.

Before these species are dealt with, it seems advisable to provide certain background information. The Johnston collections were originally made to check whether the endemic Hawaiian fishes were really species or merely subspecies. It was felt that intergradation between the Hawaiian endemics and their Central Pacific counterparts would occur at Johnston if anywhere. It does not occur there (or elsewhere) among any of the fishes here investigated, and on the basis of absence of intergradation (the term is here used in contrast with introgression) the Hawaiian endemics must be considered full species. But would the Hawaiian endemics interbreed with their Central Pacific counterparts if both were present? There is no way of determining this at Johnston, because the two never occur together there (or elsewhere). When a Central Pacific fish is represented by a variant in Hawaii, either the Central Pacific form (e.g., *Kuhlia marginata*) or the Hawaiian form (e.g., *Muraenichthys cookei*, *Gymnothorax eurostus*, *Cirrhitus alternatus*, *Chaetodon multicinctus*, and *Acanthurus sandvicensis*), or neither, but not both, occurs at Johnston. That this proves nothing regarding the interbreeding potentialities of the two geographic forms has been discussed in an earlier paper (Gosline, In press). The failure to be able to determine whether interbreeding between the Hawaiian endemics and their Central Pacific counterparts would or does occur makes it impossible to prove whether the Hawaiain forms are full species or merely subspecies. This matter has also been discussed elsewhere (Gosline, *op. cit.*). The point here is that the failure to settle the matter has led to considerable zoogeographic misunderstanding concerning endemism in the Hawaiian inshore fish fauna. For example, Jordan and Evermann (1905: 32) conclude that about 50 per cent of the species of Hawaiian shallow water fishes are endemic; Fowler's (1928) treatment of the same fishes would give a far lower percentage of endemism, perhaps 15 per cent. This appears to be a disagreement concerning the number of endemic Hawaiian fishes, but in reality it is a difference in viewpoint regarding how many Hawaiian endemics should be treated as full species. That one viewpoint is correct and the other incorrect will probably never be proved. About all that can be said is that in general the Hawaiian offshoots of Indo-Pacific species are more distinctive than those that occur anywhere else. Since I believe that Jordan and Evermann's interpretation of Hawaiian endemism in fishes brings out this point more clearly than Fowler's and since no real intergradation can be demonstrated between Hawaiian and Central Pacific forms, it seems preferable to side with Jordan and Evermann.

Muraenichthys cookei–laticaudata

The Hawaiian form, *Muraenichthys cookei*, was described by Fowler (1928: 41, fig. 9). In 1943 Schultz (p. 53) synonymized Fowler's species with *Muraenichthys laticaudata* (Ogilby) described from Fiji. In 1949 Schultz and Woods (p. 172) recognized both species, differentiating them on the basis of the more anterior position of the dorsal origin in relation to the anus in *M. cookei*. The same basis of differentiation is used by Schultz (in Schultz, *et al.*, 1953: 72–73). No other differences between the two species are known. The relationship between the dorsal origin and the anus in specimens of the *M. cookei–laticaudata* complex from several localities is shown in Table 3. (In the table total lengths have not been given since there is no evidence of a change in the dorsal–anus relationship with growth.) Several points can only be suggested by this table since the within-sample variabil-

TABLE 3

THE RELATIONSHIP BETWEEN THE DORSAL ORIGIN AND THE POSITION OF THE ANUS IN SPECIMENS
OF THE *Muraenichthys cookei–laticaudata* COMPLEX

Distances are expressed in thousandths of the standard length. Plus values indicate distances of the dorsal origin
in front of the anus; minus values, distances behind the anus

SPECIES AND LOCALITY	NUMBER OF SPECIMENS	DISTANCE FROM ANUS	
		Average	Range
Muraenichthys laticaudata			
Marshalls........................	3	−26	−80 to + 11
Muraenichthys cookei			
Hawaiian Islands			
Midway......................	7	12	0 to + 23
Oahu........................	7	20	+ 3 to + 39
Johnston.....................	12	50	+15 to +116

ity is high and the available specimens from any one locality few. First, the two "species" cannot always be separated on the basis of the dorsal origin, for the ranges of the Marshallese and Midway specimens overlap. Second, the Marshallese *M. laticaudata* is most like the Midway form of *M. cookei*, which becomes progressively more distinct at Oahu and Johnston. One would like to know the nature of the populations of this species complex at Wake, a northern outlier of the Marshalls and somewhat between the rest of the group and Midway, but it has never been taken there. One would also like to know about the Line Island populations, but again the species complex is unrecorded from there. In the absence of evidence from these rather crucial localities, one can only speculate that the complex moved into Hawaii from the west, becoming further and further differentiated as it moved down the chain and thence to Johnston. Whatever the derivation, the fact remains that in the habitat (Johnston) that most resembles that of the presumably ancestral *M. laticaudata* the differentiation is the greatest and in the habitat that least resembles the Central Pacific (Midway) the differentiation has been least. Thus the character by which *M. cookei* is distinguished from *M. laticaudata* cannot be explained as an adaptation to a cold-water environment; it would seem rather to be an instance in which differentiation has proceeded independently of the environment.

Gymnothorax eurostus–buroensis

The Hawaiian *Gymnothorax eurostus* is very similar to the Central Pacific species which has been called in recent years *G. buroensis*. Schultz (in Schultz, *et al.*, 1953: 120) has separated the two on the basis of minor color differences. The most important of these is the mottling of the lower jaw in *G. eurostus* as contrasted with the plain throat and lower jaw of *G. buroensis*. Unfortunately, *G. eurostus* at least is very variable in coloration, and almost any color character breaks down in some individuals. The color differentiation of the two species can, however, be supplemented by a number of morphological characters, but for each of these there are, again, individual exceptions. At any given size over perhaps 7 inches, *G. buroensis* is a chunkier fish, and the head especially is higher and blunter, but both species become more heavy-bodied with age. (This and other proportional characters do not seem worth stating quantitatively because of the difficulty of obtaining reliable measurements on morays.) The mouth of *G. buroenis* closes completely; that of *G. eurostus* does not, leaving a gap between the lips just ahead of the eye when the jaw

tips are tightly closed. The length of the snout is usually less than the distance from the eye to the rictus in *G. buroensis*, greater in *G. eurostus*. The fifth pore from the front on the chin is usually behind the most posterior pore on the upper lip and behind the eye in *G. buroensis*, under or in front of the last pore of the upper lip and under the eye in *G. eurostus*. There are fewer teeth in the jaws of *G. buroensis* than of *G. eurostus*, but since adult morays usually lose teeth this character again does not seem to merit quantitative analysis. Finally, *G. buroensis* is definitely the smaller of the two species: the largest of several hundred specimens of *G. buroensis* taken by Schultz in the Marshalls (Schultz, *et al.*, 1953: 118) was about 13 inches; the largest of 20 specimens of *G. eurostus* taken by me in Johnston is 20 inches long. In sum then, the two species are rather easy to separate for anyone familiar with them, even though there is no single character on the basis of which it would be possible to correctly identify all specimens.

Due to the nature of the differences between the two species it can only be stated without adequate demonstration that all specimens of this complex from Johnston are typical *G. eurostus*. Specimens from Christmas, in the Line Islands to the south of Johnston, seem to be typical *G. buroensis*. All of the hundreds of specimens from the Hawaiian Islands seen by me, with one exception, are *G. eurostus*. The exception consists of specimens taken by Mr. Tinker of the Honolulu Aquarium from among the heavy fouling on the bottom of a barge that was put in drydock at Pearl Harbor (see Chapman and Schultz, 1952: 528, Edmondson, 1951: 212). The eel that dropped out of this fouling is a typical specimen of *G. buroensis*. Inasmuch as several other fishes, crustacea, and mollusks taken from this fouling have never been recorded elsewhere in Hawaiian waters, and inasmuch as the barge had been towed in from Guam, it seems logical to presume, despite Chapman and Schultz, that these alien forms came in

with the barge from somewhere in the Central Pacific.

Kuhlia sandvicensis–marginata

Despite previous accounts (e.g., Fowler, 1949: 83) there seems to be only one species of *Kuhlia*, namely *K. sandvicensis*, represented in the Hawaiian chain. This species is closely related to *K. marginata* from the Central Pacific, with which it will here be compared. Before doing so it seems well to mention that from published accounts (e.g., Ikeda, 1939: 131–158) *K. boninensis* from the Bonin and Riu Kiu Islands also seems to be near *K. sandvicensis*.

According to Schultz (in Schultz, *et al.*, 1953: 325) *K. marginata* differs from *K. sandvicensis* in having somewhat higher average pectoral and dorsal counts. However, the two species also differ in the number of gill rakers, and it is these that will be emphasized in this analysis.

In the number of dorsal rays, my counts of *K. sandvicensis* agree more closely with Schultz's counts of *K. marginata* than with his data for *K. sandvicensis* (Table 4). Under the circumstances there seems no point in following the analysis of this character further.

The total pectoral ray counts in certain samples of the *K. sandvicensis–marginata* complex are summarized in Table 5. Several aspects of this table warrant discussion. In the

TABLE 4

Dorsal Soft Ray Counts in the *Kuhlia sandvicensis–marginata* Complex

SPECIES AND LOCALITY	NUMBER OF SPECIMENS	AVERAGE COUNT
K. sandvicensis		
Hawaiian Islands		
Midway..........	25	11.08
French Frigate.....	5	11.00
Kauai...........	25	11.08
Oahu...........	25	11.04
Oahu (Schultz)....	9	11.55
K. marginata		
Johnston (Schultz)...	2	11.00
Marshalls (Schultz)..	10	11.00

first place the several small samples available from Midway vary considerably in average count. What this means is not clear, but it has prevented me from placing too much faith in the results of single larger samples from elsewhere. If one were to exclude the samples from the low Hawaiian Islands (Midway, Lisianski, and French Frigate) one would obtain a correlation between increase in pectoral count and decrease in water temperature for the species complex. On the other hand, if one considered the samples of *Kuhlia sandvicensis* alone, one would obtain a correlation in the reverse direction. An attempt to explain these contradictory trends will be made after consideration of the gill-raker data. Meanwhile, it may be noted that the Johnston fishes appear to be of almost pure Central Pacific stock.

Before proceeding with the gill-raker information, three features should be noted. In the first place, as Schultz (1943: 99) has observed, the young of *Kuhlia* have fewer gill rakers than the adult. By plotting the number of gill rakers against standard length in certain large Hawaiian samples, it was determined that *K. sandvicensis* obtains approximately its full gill-raker complement by about 40 millimeters in standard length. Consequently no fish smaller than 40 millimeters were used in the data which follow. The second point regards the method of making counts. In *Kuhlia* the most anterior one of two rakers frequently taper to almost nothing, and it seems preferable to count only the developed gill rakers. Here, then, only the pectinate rakers are counted; the shorter, nob-topped rakers are omitted. Even this restriction leaves some specimens in which the count remains somewhat questionable. To check the consistency in my own counting, the gill rakers in a sample of 37 fish were recounted at the end of a year. The original count gave an average of 24.41, the later count, 24.57. These and all other counts used here are only those below the angle (excluding the raker at the angle).

TABLE 5

TOTAL PECTORAL RAY COUNTS IN SPECIMENS OF THE
Kuhlia sandvicensis–marginata COMPLEX

SPECIES AND LOCALITY	NUMBER OF SPECIMENS	AVERAGE COUNT
K. sandvicensis		
Hawaiian Islands		
Midway (Mar., 1949)	7	14.57
Midway (July, 1949)	12	14.91
Midway (June, 1950)	6	14.33
Midway (May, 1951)	3	15.00
Midway (all specimens) ..	28	14.72
Lisianski..........	3	14.33
French Frigate.....	5	14.60
Kauai	10	14.80
Oahu	25	14.76
Oahu (Schultz)....	17	15.00
Hawaii	22	15.00
K. marginata		
Johnston...........	9	14.00
Line Is.: Palmyra	2	14.00
Wake.............	20	14.00
Marshalls (Schultz) ..	10	13.71

Pectinate gill rakers on the lower limb of the first arch range from 22 to 28 in my samples of *K. sandvicensis*, from 24 to 29 in the smaller numbers of *K. marginata* examined. It seems well to discuss the *K. sandvicensis* samples first, as these are both the largest and the most numerous. In the first place it seems as if those samples containing small fish have somewhat lower average counts than the samples with large fish (Table 6). Perhaps the gill raker number does continue to increase above 40 mm.

With this in mind, the pairs of samples from the same island may be compared. The two Oahu samples were taken in different years from exactly the same tide pool. The difference between the means of these two samples is 0.41. The two samples from Hawaii are of an entirely different sort. One was taken from fresh water, the other from the sea. The difference between the means of these samples is 1.50 gill rakers, though part

of this difference may be attributable to the different sized specimens in the sample. At any rate, it seems from the above data that (presumably) environmental differences within areas may play a considerable role in the differentiation of gill raker counts, and this must be kept in mind in assessing the biological significance of the difference between samples.

Even allowing for this variability within areas, the gill raker counts for *K. sandvicensis* at Midway seem to be considerably higher than for other areas. The increase in Midway counts over those of Pearl and Hermes reef some 90 miles away is especially curious.

Among the samples of *K. marginata* about all that can be said is that the counts for the Johnston and Wake specimens seem to be particularly high. On the other hand the few counts from Penrhyn, about as far south of the equator as Johnston and Wake are north, are low. Any attempt to correlate gill-raker

counts with water temperatures in this species complex on the basis of the present material seems fatuous.

Summing up the data for the *Kuhlia sandvicensis–marginata* complex, it may be said that the Johnston and Wake samples show absolutely no indication of introgression from the Hawaiian species so far as gill-raker counts are concerned. Conversely, the samples from the high Hawaiian islands show no sign of intermixing from *K. marginata*. However, the low Hawaiian island samples, particularly those from Midway, show a trend toward the southern form. Since Midway has the water temperatures and total environment least like those of the areas in which *K. marginata* lives, the similarity of the Midway *K. sandvicensis* to *K. marginata* can best be explained by introgression from the latter species. Whether such introgression is brought about through specimens of *K. marginata* coming in from Johnston, Wake, Marcus or elsewhere remains unknown.

TABLE 6

THE NUMBER OF PECTINATE GILL RAKERS ON THE LOWER LIMB OF THE FIRST GILL ARCH IN SAMPLES OF THE *Kuhlia sandvicensis–marginata* COMPLEX

SPECIES AND LOCALITY	NUMBER OF SPECIMENS	AVERAGE COUNT	STANDARD DEVIATION	AVERAGE STANDARD LENGTH IN MM.
K. sandvicensis				
Hawaiian Islands				
Midway (July, 1949)	25	25.40	1.24	61.0
Midway (June, 1950)	29	25.28	0.80	over 100*
Pearl and Hermes	22	24.18	0.73	over 100*
Lisianski	39	24.41	0.75	over 100*
French Frigate	5	24.20		61.8
Kauai	25	24.64	1.25	135.6
Oahu (Waimea, 1948)	37	24.41	0.75	69.6
Oahu (Waimea, 1949)	33	24.82	0.73	62.6
Hawaii (Puna Coast)	22	24.77	0.87	47.0
K. marginata				
Johnston	9	27.33	0.50	180.0
Line Is.: Palmyra	5	26.40		156.6
Phoenix Is.: Canton	3	26.00		198.3
Cook Is.: Penrhyn	6	25.67		71.8
Wake	18	27.20	1.24	121.0
Marcus	5	26.00		84.8

* Large specimens discarded in field.

In view of what has been said above, a hypothetical explanation can be given for the relationship between pectoral counts and sea temperatures. The basic assumption is that pectoral counts in this species complex increase with decreasing temperatures. In partial isolation the Hawaiian island populations would then have developed distinctly higher pectoral counts. These would be higher at Midway at the northern end of the chain than at Hawaii at the southern. However, recent introgression from *K. marginata* at Midway could have upset this trend within the Hawaiian chain, giving rise to the reversed picture for pectoral counts within the Hawaiian Islands shown in Table 5.

The fact remains that there is more difference between the *Kuhlia* populations in Johnston and Hawaii, which are almost similar in latitude, than between those of Johnston and Midway, which are very different. The conclusion seems inescapable that if members of the Johnston populations have entered the Hawaiian Islands at all, they have come in via the low northern islands. Why the Central Pacific form of *Kuhlia* rather than the endemic Hawaiian form should be present at Johnston remains a mystery. It does, however, bear out the point, previously established, that some elements of the Johnston biota have entered from the south.

Cirrhitus alternatus–pinnulatus

The two forms in this complex have recently been differentiated by Schultz (1950: 548), but entirely on the basis of coloration, the Hawaiian *C. alternatus* lacking the brown spotting of the Central Pacific species. A check of the usual meristic characters in specimens from Hawaii, Johnston, and Christmas (in the Line Islands) shows no significant differentiation. As Schultz has already pointed out (*loc. cit.*), the Johnston specimens agree completely with the Hawaiian form.

Chaetodon multicinctus–punctato-fasciatus

This species pair has been separated by Woods (in Schultz, *et al.*, 1953: 571, 575,

595) on the basis of coloration and certain counts. The color differences lie chiefly in the nature of the vertical dark bars on the nape and caudal peduncle. The fin ray differences are shown in Table 7. Woods (*loc. cit.*) has also used scale counts, but I have not been able to make sufficiently accurate scale counts in this species to be worth recording.

The Johnston specimens agree with the Hawaiian form in both color and counts.

Acanthurus sandvicensis–triostegus

The *Acanthurus triostegus* complex lends itself admirably to geographic analysis for two reasons. First, its forms are abundant and ubiquitous throughout much of the tropical Indo-Pacific, and, second, they differ in characteristics that are easily seen and calibrated. A preliminary analysis of geographic variation in this complex has recently appeared (Schultz and Woods, 1948: 248–251). According to these authors two species are represented: *Acanthurus sandvicensis* in the Hawaiian Islands and at Johnston, and *A. triostegus* throughout the rest of the area. The differences between these two lie primarily in the shape and extent of the mark below and at base of the pectoral, secondarily in the higher average fin counts of the Hawaiian species.

The Johnston Island population, judging from 21 specimens taken in three Johnston localities, differs in no way that I can determine from the Hawaiian form. If there is any admixture of *A. triostegus* genes in these Johnston specimens, it is not apparent. If, however, populations of the *A. triostegus* complex from the next island groups to the south of Johnston are examined an occasional specimen turns up with more or less strong traces of the Hawaiian pectoral base marking. For a study of possible intergradation between the Hawaiian *A. sandvicensis* and the Indo-Pacific *A. triostegus* it seems advisable therefore to focus attention not on Johnston but on the Line and Phoenix Islands to the south of Johnston.

TABLE 7

FIN COUNTS IN SPECIMENS OF THE *Chaetodon multicinctus–punctato-fasciatus* COMPLEX

SPECIES AND LOCALITY	DORSAL SOFT RAYS					ANAL SOFT RAYS			PECTORAL*		
	22	23	24	25	26	17	18	19	13	14	15
C. *multicinctus*											
Hawaiian Islands (Woods)			1	7			3	6		5	4
Honolulu.............			1	4	1		3	3		3	
Johnston..............			1	1	1		1	2		3	
C. *punctato-fasciatus*											
Marshalls (Woods).......	1	2	6	1		4	6		2	6	

* Splint at top of pectoral fin not included.

In color pattern three rather distinctive types have been distinguished in the Central Pacific. (1) In the Marshalls (according to Schultz and Woods, *op. cit.*, p. 250, table 1) specimens of *A. triostegus* almost always have a single spot at the upper end of the pectoral fin base. In addition (Schultz and Woods, in Schultz, *et al.*, 1953: 625) the black marking on the caudal peduncle is "represented by a spot on dorsal and ventral sides, or a saddle, sometimes absent except for a small spot on dorsal surface only, never completely across side of caudal peduncle." (2) *Acanthurus sandvicensis* consistently has a dark bar across the pectoral base, which is continued downward and somewhat backward on the body. On the caudal peduncle there is a black saddle which extends one third to one half way down the side of the peduncle; there is no spotting below this saddle. (3) In the Marquesas (according to Schultz and Woods, 1948, *loc. cit.*) *A. triostegus* consistently has two spots at each pectoral base, one at the upper part of the base as in the Marshallese form, and another on the body just below the base. These two spots are connected in the young. The caudal saddle in the Marquesan specimens is usually as in the Marshallese form but, in 6 out of 18 specimens, "extending down sides of caudal peduncle and joining with spot on lower sides" on at least one side of the body (Schultz and Woods, 1948, *loc. cit.*). All of the three color types cited above may be found in specimens from Line and

Phoenix Island samples in addition to variants not apparently found elsewhere. Quite frequently markings characteristic of two different races occur on the two sides of the same Phoenix or Line Island fish.

If a stripe running down on to the body below the base of the pectoral fin is designated as A, a single spot on the upper part of the pectoral fin base as B, two spots, one on and one below the fin base as C, and a bar across, and limited to, the fin base as D, Table 8 may be prepared. (The A, B, C, and D types are essentially those similarly designated in Schultz and Woods (1948: 249 and in Schultz, *et al.*, 1953: 625). Actually the four types are not sharply distinct in Phoenix and Line Island fishes. In these areas the A type band extends only slightly below the pectoral base (about as in type E of Schultz and Woods and not well below as in *Acanthurus sandvicensis*) and thus can only be distinguished by definition from D. Furthermore in a few specimens the lower part of the stripe of A tends to become separate and thus grades into C. Finally an elongate spot (B) grades into a bar (D).)

From this table it may be seen that between these two samples all combinations of the different types of pectoral marking may and do occur on opposite sides of the same fish. Indeed, 16 out of 60 specimens have different types of pectoral markings on the two sides of the body. The instability in these populations of the types of pectoral markings that

are elsewhere nearly constant is excessive.

If one considers B to be the pure Marshallese form, C to be the Marquesan, and A and D a tendency toward the Hawaiian species, then the table may be recalculated as is done in Table 9.

Table 9 demonstrates the unity in pectoral markings of the two samples from the northern Line Islands (Christmas) and the southern Phoenix Islands (Hull). These two islands are, incidentally, some 800 air miles from one another. Also, if types B and D really are a tendency towards *A. sandvicensis*, some indication of intergradation with the Hawaiian species seems present in both samples.

Summarizing the data on pectoral markings in the Phoenix–Line populations, it may be said that these contain to some degree all the marking types to be found in the more constant races to the west (Marshallese), north (Hawaiian), and southeast (Marquesan).

In regard to caudal peduncle markings, a similar concentration of variability in the Phoenix and Line Island samples could probably be demonstrated. However, an analysis of the caudal markings suffers from the two facts that the Marshallese and Marquesan races are not particularly constant in this feature and that the Hawaiian marking is to some extent intermediate between the Marquesan and Marshallese pattern. Suffice it, then, to say here that the same bilateral asymmetry in the coloration on the caudal peduncle takes place as occurs in the pectoral marking, that there does not seem to be any correlation between the shape of the marks on the caudal peduncle and those at the pectoral bases, and finally that there are again all gradations between the various types of caudal markings.

The other feature used by Schultz and Woods (*op. cit.*) in separating the forms of the *Acanthurus triostegus* complex is the dorsal, anal, and pectoral fin counts. The Hawaiian species was found to have higher average sample values for each of these fins than samples from elsewhere. Schultz and Woods

go on to note that the somewhat lower water temperatures of the Hawaiian area may be responsible for this.

Dorsal, anal, and pectoral counts of certain samples from the Hawaiian, Line, and Phoenix Islands, along with the average annual water temperatures (as calculated from Charts II and III at the back of Sverdrup, Johnston, and Fleming, 1946) are shown in Table 10. Several points about this table need discussion. The first regards variation within areas. Thus, two samples from the single island of Oahu have an average difference of nearly 0.2 of a dorsal ray. Indeed, one suspects that different populations from the same area might differ by perhaps 0.3 dorsal ray, 0.2 anal ray, and 0.1 pectoral ray, though available data is insufficient to prove this. At least nothing less than such amounts should be considered geographically significant. Second, the various island groups investigated seem to have rather different average counts, as summarized in Table 10. The Phoenix (Hull Island) sample, well to the south of the Line Islands and still farther away from Hawaii seems to be intermediate between the Line and Hawaiian Island samples. Another Phoenix Island lot counted by Schultz and Woods (1948: table I) indicates the same thing. Certainly, no genetic intermixing between the Hawaiian and Line Island samples is indicated. If one attempts to explain the change in average count by temperature effect, the Line Island samples create the same stumbling block as for introgression, for temperatures in the Phoenix Islands seem to be higher (and should therefore give lower, not higher, average counts than for the Line Island lots).

Summarizing for the *Acanthurus sandvicensis–triostegus* complex, the following points may be made. There is no sign of intergradation between *A. sandvicensis* and *A. triostegus* at Johnston; the pure Hawaiian form is represented there. In the Line and Phoenix Island samples there is some indication of the *A. sandvicensis* pectoral marking in some speci-

TABLE 8

TYPES OF MARKINGS AT PECTORAL BASE IN PHOENIX AND LINE ISLAND SAMPLES OF *Acanthurus triostegus*

For explanation of lettering, see text

LOCALITY	AA	AB	AC	AD	BB	BC	BD	CC	CD	DD
Line Is.: Christmas...............	1	0	1	1	15	1	4	3	0	1
Phoenix Is.: Hull................	4	2	0	1	17	2	3	2	1	1

TABLE 9

TYPES OF MARKINGS AT PECTORAL BASE IN PHOENIX AND LINE ISLAND SAMPLES OF *Acanthurus triostegus*

LOCALITY	"MARSHALLESE"	"MARQUESAN"	"HAWAIIAN"
Line Is.: Christmas..................	35 (65%)	8 (15%)	11 (20%)
Phoenix Is.: Hull...................	41 (52%)	7 (11%)	18 (27%)

mens. That introgression of *A. sandvicensis* genes into these populations has occured via passage of Hawaiian individuals through the Line Islands is contra-indicated by the average fin counts of Line Island samples.

Results of the Species Analyses

Though the nature of the available material precludes very extensive cross comparisons between species, a certain amount of integration between the results of the various species can be made.

The first point regards the nature of the morphological distinctions of the Hawaiian endemic forms. In an earlier paper (Gosline, In press) it was stated: "In morphological features the Hawaiian endemic fishes show no pattern of divergence from their Central Pacific relatives." However, in view of Strasburg's recent paper (1955) demonstrating that in the *Istiblennius edentulus* complex there is a rather close correlation between fin ray count and water temperature, it seems well to reinvestigate this statement. Among the six species pairs dealt with here, four differ in coloration, three in meristic counts, one in the position of the dorsal origin, and one in the shape of the head. Of those differing in color, *Gymnothorax eurostus* is separable primarily on the basis of the mottling of the

throat, *Cirrhitus alternatus* in the absence of brown spots on the body, *Chaetodon multicinctus* in the presence of more prominent barring on the nape and caudal peduncle, and *Acanthurus sandvicensis* in the long curved streak below the pectoral base. There seems to be no pattern of differentiation here. However, a pattern does emerge from the meristic data. Of those species pairs differing in meristic characters, two of the Hawaiian endemics have more pectoral rays (*Kuhlia sandvicensis* and *Chaetodon multicinctus*), two have more dorsal and anal soft rays (*Chaetodon multicinctus* and *Acanthurus sandvicensis*), and one has *fewer* gill rakers (*Kuhlia sandvicensis*). Thus for fin rays, if not for gill rakers, there does seem to be a trend toward higher meristic counts in these Hawaiian endemics. Other species showing the same trend that are not dealt with here are *Istiblennius zebra* (see Strasburg, *op. cit.*) and *Dascyllus albisella*. However, what has just been said should not obscure the fact that there are many species in which the Hawaiian form shows no increase in counts and at least a few in which a decrease occurs. Thus the Hawaiian trichonotid *Crystallodytes cookei* differs from its Phoenix Island counterpart only, so far as known, in having *fewer* dorsal and anal rays (Schultz, 1943: 266), and the Hawaiian gobioid *Kraemeria bryani* differs

TABLE 10

FIN COUNTS FOR CERTAIN SAMPLES OF THE *Acanthurus sandvicensis–triostegus* COMPLEX

For the counts averages are given above and standard deviations below in parentheses. No standard deviations
were calculated for the counts drawn from Schultz and Woods (1948: table 1)
as these appear to represent combined samples

LOCALITY	AVERAGE ANNUAL SURFACE WATER TEMPERATURE	NUMBER OF SPECIMENS	SOFT DORSAL RAYS	SOFT ANAL RAYS	TOTAL PECTORAL RAYS
Hawaii: Midway....................	22.0° C	18	23.33 (±.57)	20.67 (±.57)	15.89 (±.33)
Hawaii: Oahu (tide pool on exposed NW coast)......................	24.5	20	23.45 (±.55)	20.75 (±.58)	15.85 (±.36)
Hawaii: Oahu (reef-enclosed bay).....	24.5	46	23.28 (±.62)	20.67 (±.47)	15.83 (±.38)
Hawaii and Johnston (from Schultz and Woods)......................		32	23.59	20.84	15.84
Johnston...........................	26.0	21	23.47 (±.60)	20.67 (±.80)	15.81 (±.40)
Line: Palmyra.....................	26.8	36	22.78 (±.59)	19.58 (±.92)	15.50 (±.50)
Line: Christmas....................	26.1	26	22.46 (±.51)	19.46 (±.58)	15.46 (±.51)
Phoenix: Hull.....................	27.3	33	23.03 (±.52)	20.00 (±.49)	15.45 (±.50)
Phoenix (from Schultz and Woods)...		11	23.09	20.36	15.37*
Guam, Marshalls (from Schultz and Woods)......................		21	22.81	20.14	15.19

* Based on 16 specimens.

from its tropical relative *K. samoensis* most significantly in the *lower* number of pectoral rays (Schultz, 1943: 262).

Zoogeographically there are few definite conclusions that can be drawn from the species analysis, though there are several indications. One of the species, *Kuhlia marginata*, has obviously come to Johnston from the south; the other five have come down from the north. The southern *Kuhlia* shows distinct signs of having introgressed into the northwestern Hawaiian Island populations of *K. sandvicensis*, though whether this has been due to immigration from Johnston or elsewhere remains unknown. Since, however, the prevailing current system around Johnston is from east to west, and even northwest, it seems probable that any migration from Johnston would reach the western leeward

Hawaiian Islands rather than the eastern windward islands. Because of this same current system, any Hawaiian fishes arriving at Johnston would probably have come in from the eastern rather than the western islands, and this is what appears to have happened with *Muraenichthys cookei*, judging from the data presented on that species. That Hawaiian endemics, such as *M. cookei*, have gotten from the Hawaiian Islands to Johnston seems certain. That Johnston fishes actually ever got to Hawaii remains unproven.

ZOOGEOGRAPHIC CONCLUSIONS

Although it may be repetitious, it seems well to draw together the results of the second half of this paper for the sake of those who got lost among the pectoral markings of *Acanthurus* or elsewhere.

The Johnston fish fauna is made up of four components (Fig. 4): endemics; fishes that have made Johnston a stopping point on their migrations from the south; fishes that have found Johnston as a way point in their southward travels; and pelagic fishes to whom Johnston is of little or no significance. The last category, which undoubtedly merges into the second and third, has been excluded from consideration in the present paper. The first is made up of only two species which may simply have been as yet unrecorded elsewhere; in any case, there is very little endemism at Johnston. Species that must have come in from the south, since they are as yet unrecorded in Hawaii and those known to have come in from the north, the "Hawaiian endemics," are represented in Johnston in about equal number. In terms of percentages, however, the proportion of the Hawaiian endemic fauna that reached Johnston is far higher than the proportion of the Central Pacific fauna that reached Johnston but not Hawaii. For this reason it is preferable to consider Johnston as an outlier of the Hawaiian faunal area rather than as a peripheral component of the Central Pacific faunal area.

There is no known intergradation between Hawaiian endemics and their Central Pacific counterparts at Johnston. If the Central Pacific form is represented at Johnston it is there in its pure form and the Hawaiian counterpart is absent, and vice versa.

Since many "Hawaiian endemics" are present at Johnston, it is certain that some species at least have traveled from Hawaii to Johnston. It is, however, not proven that any Johnston fishes ever got to Hawaii; nor is it proven that they did not. Consequently, the role that Johnston may have played in the development of the Hawaiian fish fauna remains in doubt. If, however, one rejects Johnston as the stepping stone by means of which the Hawaiian fishes arrived, then one is driven back on immigration routes that, at the present time, are at least equally implausible and unproven.

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